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Isentropic Compression of High Explosives with the Z Accelerator

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ISENTROPIC COMPRESSION OF HIGH EXPLOSIVES WITH THE Z ACCELERATOR

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Isentropic compression experiments (ICE) were performed on a variety of high explosives. The samples were dynamically loaded by Sandia's Z-accelerator with a ramp compression wave of 300 ns rise time and peak stress of 100-350 kbar. Sample/window interface velocities were recorded with VISAR. Experiments were performed on LX04 to obtain the stress-strain relation using a backward integration technique. Experiments were similarly performed on LX17 and the results compared to hydrodynamics calculations that used a reactive flow equation of state. Recent experiments were also conducted on single crystal HMX with the aim of detecting the phase transition believed to occur at 270 kbar.

INTRODUCTION

Isentropic compression experiments were performed on high explosives using the "square short" assembly. In this configuration pairs of samples consisting of 6 mm diameter disks of thickness 250-600 μm were placed on driver panels of aluminum of base thickness 400 μm. Windows of LiF or PMMA were bonded to the back of the HE samples to minimize wave interactions and aid in the analysis. A pressure ramp of approximately 300 ns duration and peak pressure which ranged from 100 to 400 kbar, depending on the experiment, was applied to the aluminum surface. The resulting HE/window interface velocity was recorded using single-point VISAR.

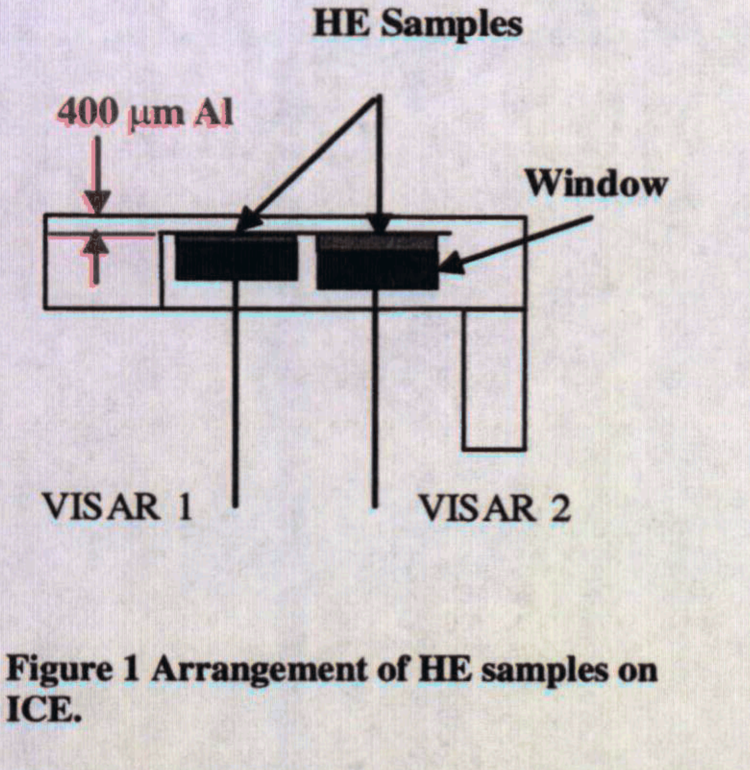


Figure 1 Arrangement of HE samples on ICE.

The pressure profile chosen was tailored to delay shock up of the sample. This was accomplished by firing 9 lines of Z's 36 lines 200 ns pulse. The pressure profile, based on B-dot measurements is shown in figure 2.

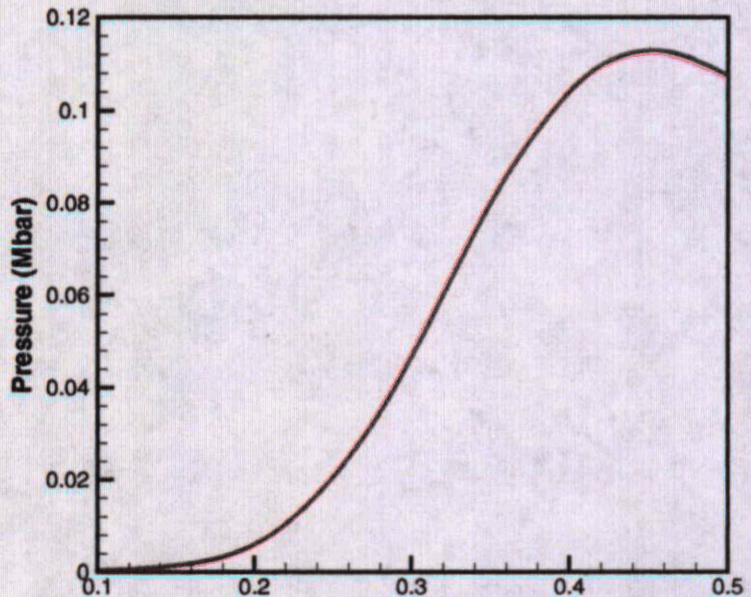


Figure 2 Pressure drive for ICE. All pressure waveforms in this work had this basic "tailored" shape.

LX04 EXPERIMENTS

Experiments were performed on LX04 to obtain the isentrope. Sample thickness pairs were chosen to be 300/500 μm and 300/600 μm. The samples were isentropically loaded up to 100 kbar.

Analysis of the samples was performed using a backward integration technique. This is an iterative technique that involves backward integrating the equations of motion to a common point in space using the velocity waveforms. In this processes two or more waveforms are integrated to a common spatial point, in this case the front surface of the sample x=0, while the EOS parameters are varied. When convergence, as measured by the pressure drives of each sample agreeing with each other, is achieved, the EOS parameters are determined. The EOS form was taken to be the Mie Gruneisan form and the parameters c_0 and s were dtermined

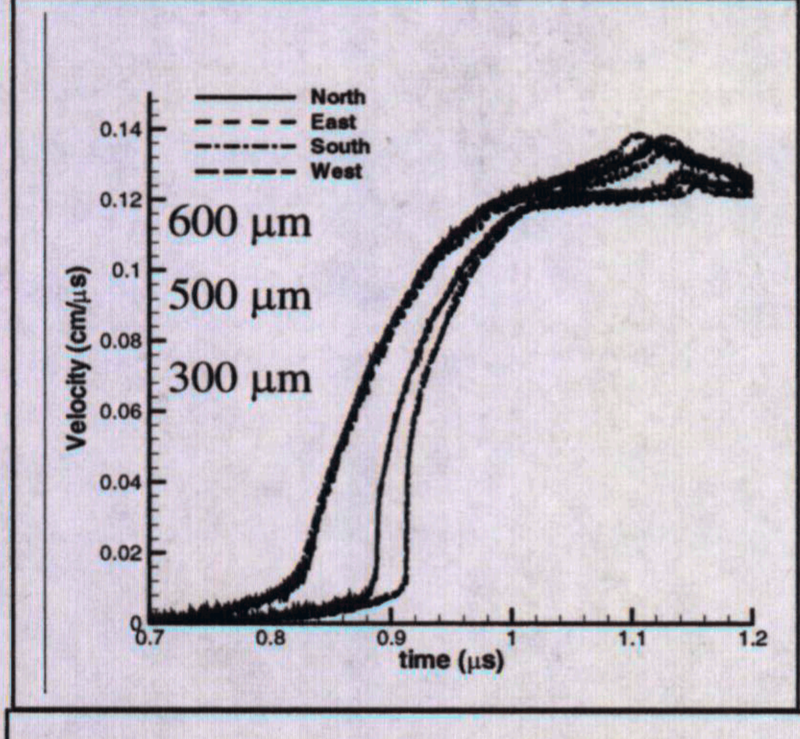


Figure 3 Velocity waveforms for LX04 experiments

This analysis was performed on two of the 300/500 sample pairs. The sample pairs with the 600 mm samples were not used as the waveforms clearly displayed a shock or steady wave which violates the reversibility assumption of the backward integration technique. A Gruneisan gamma of 0.8, determined from previous experiments, was assumed. The EOS parameters were found to be c_0=.24382 cm/μs, s=2.261. The resulting Isentrope along with the theoretical curve using the handbook values of c_0=.236 cm/μs and s=2.43 is shown in figure 4.

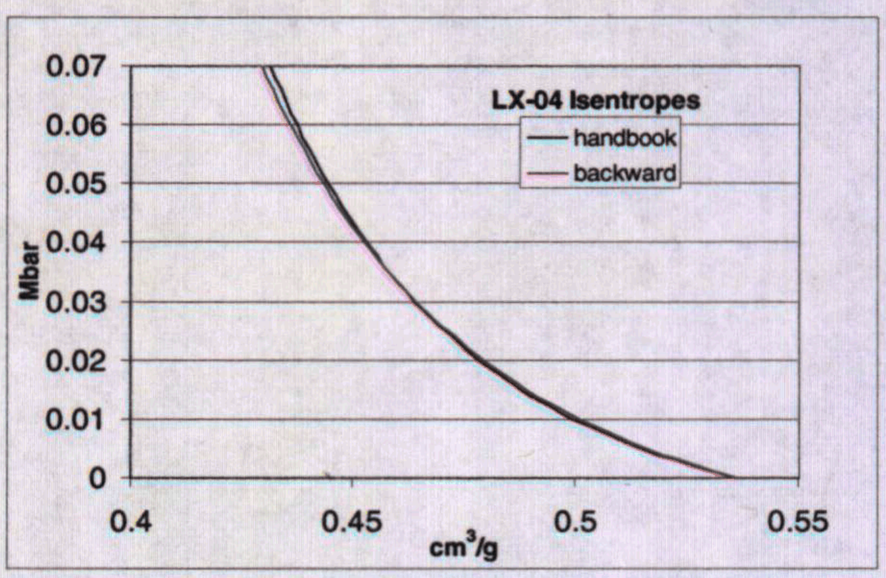
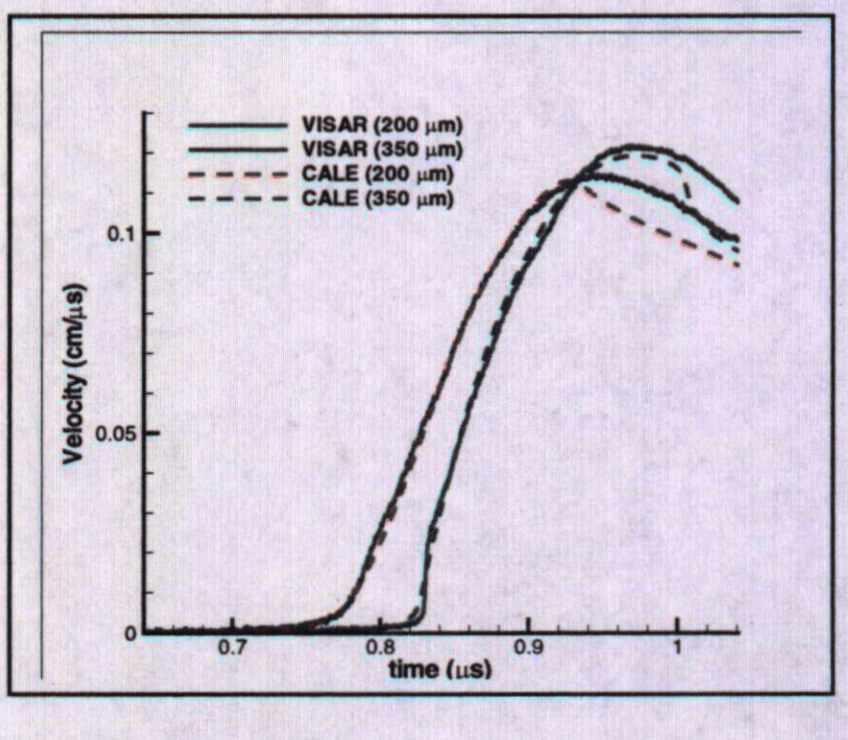


Figure 4 Results of backward integration of LX04.

LX17 EXPERIMENTS

We also performed similar experiments on LX17. Sample thickness pairs were 200/350 mm and the velocities were observed through a LiF window. The results are shown in figure 5 along with a hydrodynamic simulation performed with a reactive flow model.



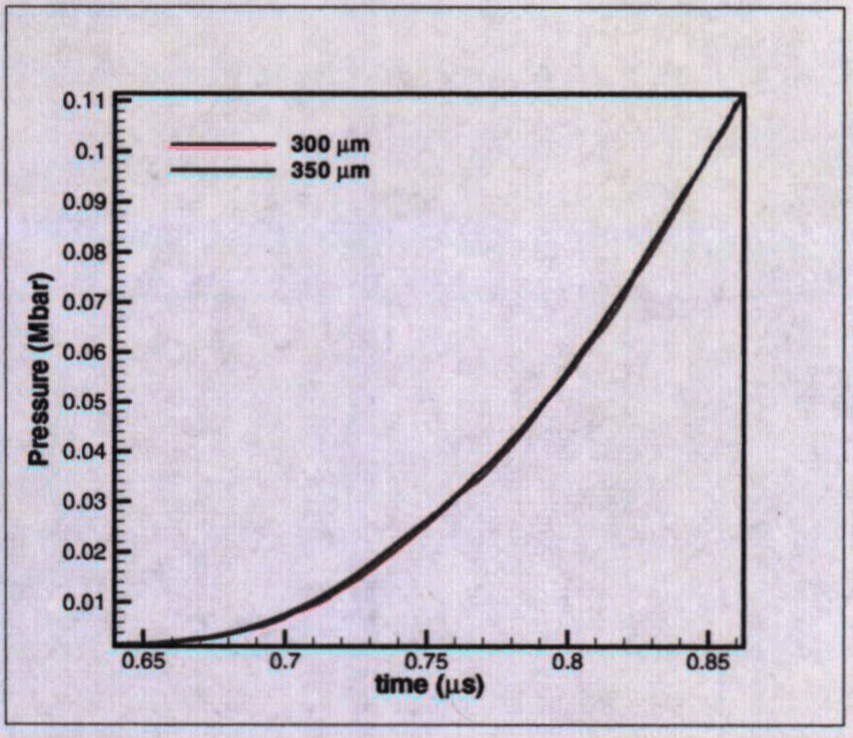


Figure 6 Backwards integration to x=0 of 300 and 350 mm LX17 samples assuming handbook values of c0 and s.

We chose to concentrate on the velocity waveforms from a 300 and 350 μm sample. Although samples of thickness ranging from 200 to 400 μm were fielded only the intermediate thicknesses could be used. The thin samples encountered a wave reverberation from release that the sample/window interface that altered the loading history. The thick samples encountered a shock that precludes their use in isentropic compression analysis.

Using the velocity waveforms from the 300 and 350 μm samples we backward integrated to x=0. Again a Mie Gruneisan model was used and we assumed the handbook values of c_0=.233 cm/ms and s=2.32. The resulting pressure waveforms at x=0 are shown in figure 6. The good convergence of both pressure drives suggests our experimental isentrope is very nearly the theoretical one based on the known values of c_0 and s.

SINGLE CRYSTAL HMX

Experiments were performed on single crystal HMX. Again, the arrangement was similar to that shown in figure 1 but slightly modified to achieve higher current densities and pressures than before. Sample thickness pairs were chosen to be 400/600 mm and 500/600 with both LiF and PMMA windoiws.

The aim of this shot was to observe dynamically the 270 kbar phase transition in HMX that was first reported under static conditions in the diamond anvil cell work of Yoo and Cynn.

Again the samples were loaded under a 250 ns tailored pressure pulse. The maximum pressure achieved in the HMX we estimate to be 400 kbar based on impedance matching to the PMMA and LiF windows.

We did not observe the characteristic two wave structure of a phase transition. However we do see inflections in the velocity curve that might indicate an abrupt change in bulk modulus with pressure.

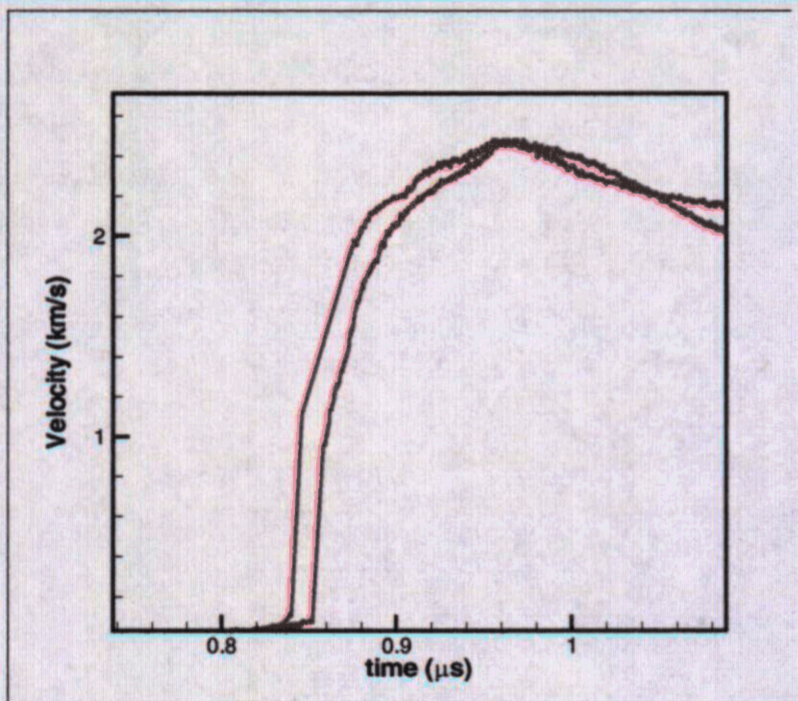


Figure 7 Velocity profiles from HMX experiments . Measurement was taken through

To guide our analysis we performed HD calculations using a modified EOS. The equation of state QEOS was used. This is global equation of state based on Thomas-Fermi theory. A modified version of this code allows the fitting of the EOS to experimental data by adding adjustable terms to the zero-Kelvin energy isotherm. This we did using the DAC data of Yoo and Cynn. The fit to the DAC data compared to a Mie Gruneisen EOS based on a linear Us-Up fit to Hugoniot data is shown in fig 8

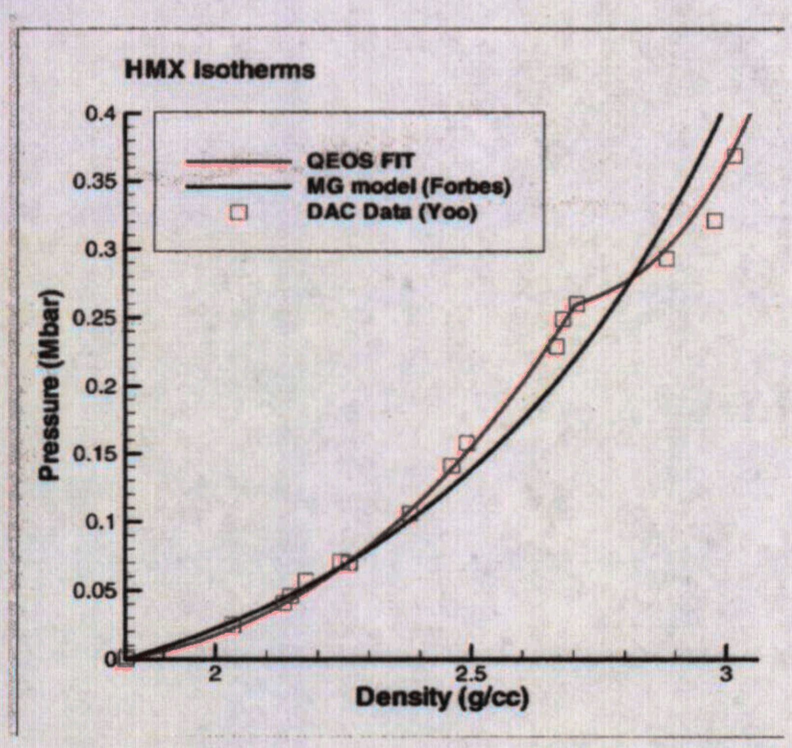


Figure 8 EOS fit used for performing HD calculations Also shown is a Mie Gruneisan model derived from a Us-Up fit to experimental data.

As before calculations were performed by assuming a pressure drive derived from experimental current measurements and scaling to the maximum pressure reached in this particular experiment.

Calculations clearly showed the classic two wave structure whereas the VISAR data did not. However, the inflections seen in the data seem to occur at the same velocity level as those of the simulation. This seems to indicate some change in compressibility, although not the sharp discontinuity of a volume collapse, in the range of the observed phase transition under static conditions.

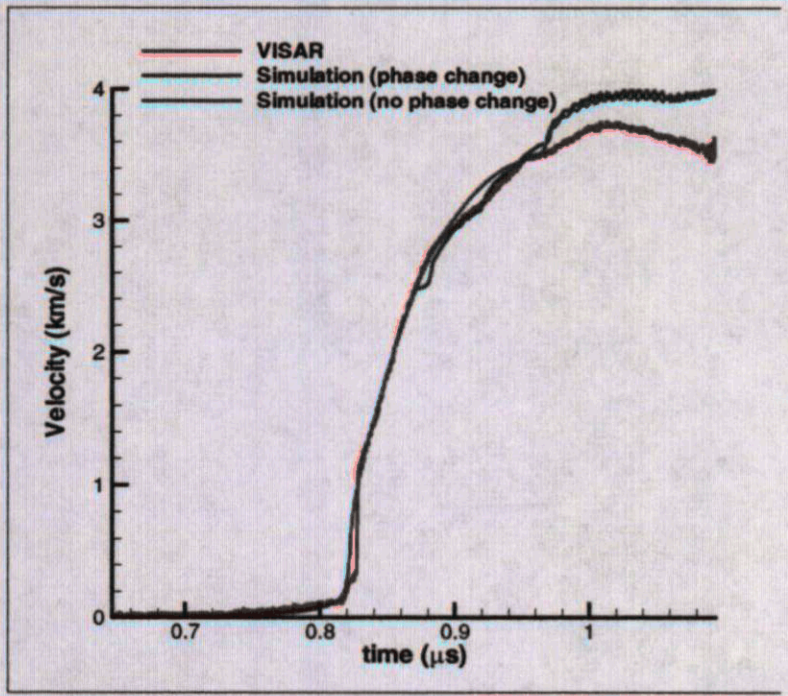


Figure 9 Velocity vs. time calculations performed with and without phase transition compared to experimental data of HMX

Future experiments will use an independent pressure drive measurement – a LiF window placed on the aluminum driver plate. This will allow us to determine conclusively if there was a change in compressibility in the 270 kbar region. We also plan to use NaCL windows on several samples. The good impedance match between NaCl and HE will allow us to eliminate possible wave effects as the source of the inflections in the velocity waveforms.

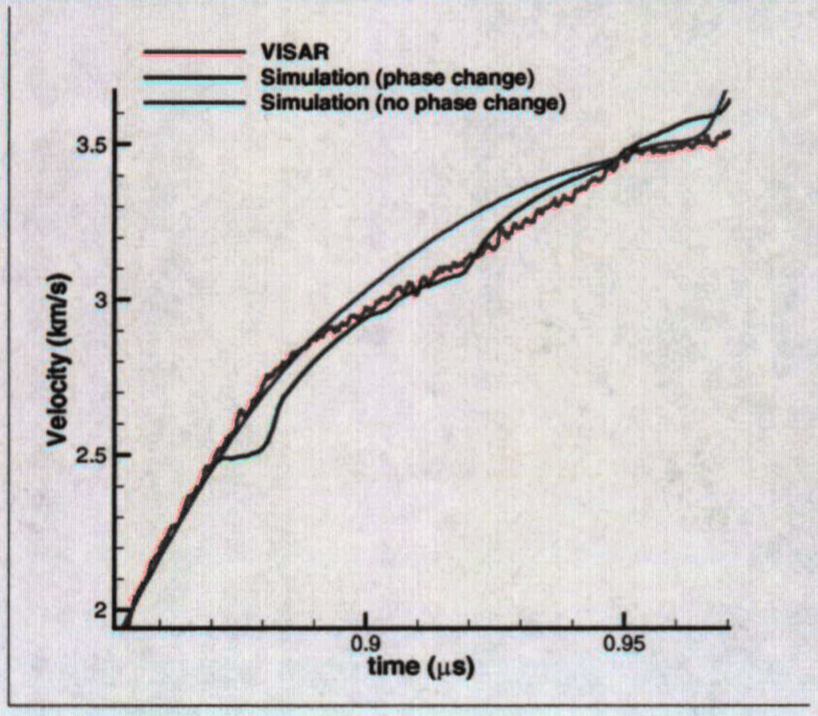


Figure 10 Close up of region of interest in figure 9. Note that calculations without phase transition do not display any inflections

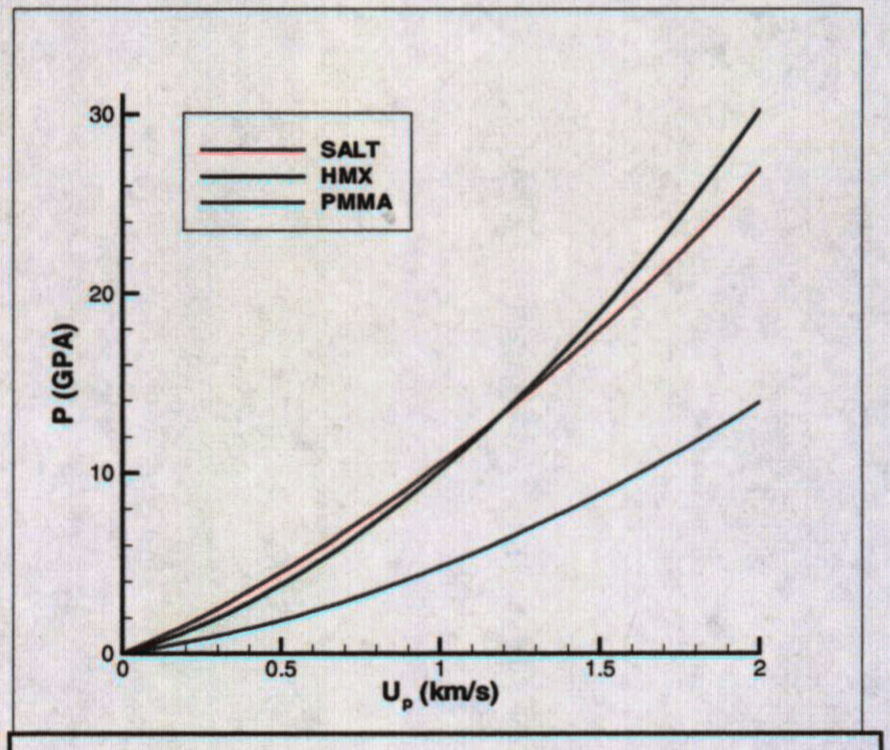


Figure 6 Compression curves of NaCl (salt), HMX, and PMMA.

CONCLUSIONS

We have performed Isentropic compression experiments on LX-04, LX-17, and single crystal HMX. We were able to extract an accurate isentrope for LX-04 and validate the reactive flow model for LX-17 under isentropic loading. Experiments with HMX seem to suggest some sort of anomalous compressibility behavior at pressures of around 270 kbars, the region where DAC data suggests a phase transition occurs. However, we do not observe a distinct two wave structure under a phase transition such as that observed in iron or bismuth. We hope to resolve these issues with future experiments.

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