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A COMPARISON OF THE SHOCK AND STATIC COMPRESSION CURVES FOR FOUR SOLID EXPLOSIVES

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ABSTRACT

For the four explosives, PETN, RDX, HMX, and TATB, comparison is made between published data for Hugoniot curves generated from shock-wave experiments and Hugoniot curves generated from isothermal static compression measurements to 10 GPa. For PETN, the static and shock Hugoniot curves in the pressure-volume plane are in agreement. From this agreement, one can conclude that the shock data for PETN determine the Hugoniot curve for unreacted material. The same conclusion can be drawn for RDX, although there is a phase transition between 4 and 5 GPa. Also for TATB the two types of data agree over their common range (0 to 7 GPa). For HMX the comparison is not as conclusive, but may indicate the presence of a phase transition in HMX above 10 GPa.

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INTRODUCTION

Over the years a good deal of shock Hugoniot data have been obtained for solid explosives[1-3] in shock initiation experiments. The data were gathered in experiments using rotating mirror cameras to record transit times or distance-time trajectories in cylindrical or wedge-shaped samples, or by using quartz gages to record stresses. In the wedge experiments, shock velocity was measured in the first few millimeters of run in the explosive and the Hugoniot state was determined by an impedance match using the measured free-surface velocity of the driver plate made of some well-characterized material, usually polymethylmethacrylate (PMMA). There has always been a question of whether the Hugoniot was an "unreacted Hugoniot" or whether some component of the shock strength was due to energy release generated by explosive decomposition.[4-6]

Olinger and coworkers of Los Alamos have published static high pressure compression curves to 10 GPa for a number of the same explosives obtained by x-ray diffraction measurements.[7-9] It seemed worthwhile to do a thorough comparison between the two types of compression curves. If they agree it indicates that the shock Hugoniot data represent the response of unreacted material. If they do not agree one may be able to get an estimate of the extent of reaction associated with the shock data. Olinger and coworkers generated Hugoniots in the shock velocity-particle velocity plane from his isotherms by assuming that the heat

capacity at constant volume and the ratio of the Gruneisen parameter to the specific volume are constants under compression, so that a direct comparison can be made. Comparison will be made here for pentaerythritol tetranitrate (PETN), cyclotrimethylene-trinitramine (RDX), cyclotetramethylene-tetranitramine (HMX), and triamino-trinitrobenzene (TATB). Shock data used will be that for the explosives in pressed polycrystalline form (less than three percent voids), in pressed, plastic-bonded form, or as single crystals.

PETN

The compression data for PETN are given in Fig. 1. The solid line is the static Hugoniot of Olinger and coworkers.[8] At 10 GPa the Hugoniot is 0.5 GPa above the isotherm. Crystal density is 1.778 g/cm^3. The shock data to 3 GPa for 1.75 g/cm^3 (1.6% voids) pressed polycrystalline material are those of Wackerle and coworkers, taken with quartz gages;[10] agreement with the static work is good as was noted by Wackerle. The shock data lie at slightly higher pressures for a given specific volume than the static curve. This is consistent with what one might expect for crushup of a porous material with strength.

In a study of PETN single crystals by the author,[11] twenty-three measurements of Hugoniot states were made for the same input shock strength; the measured stress was 8.65 ± 0.16 GPa and specific volume was 0.437 ± 0.007 cm^3/g. Shock compression was along a <110> direction. The point with error bars

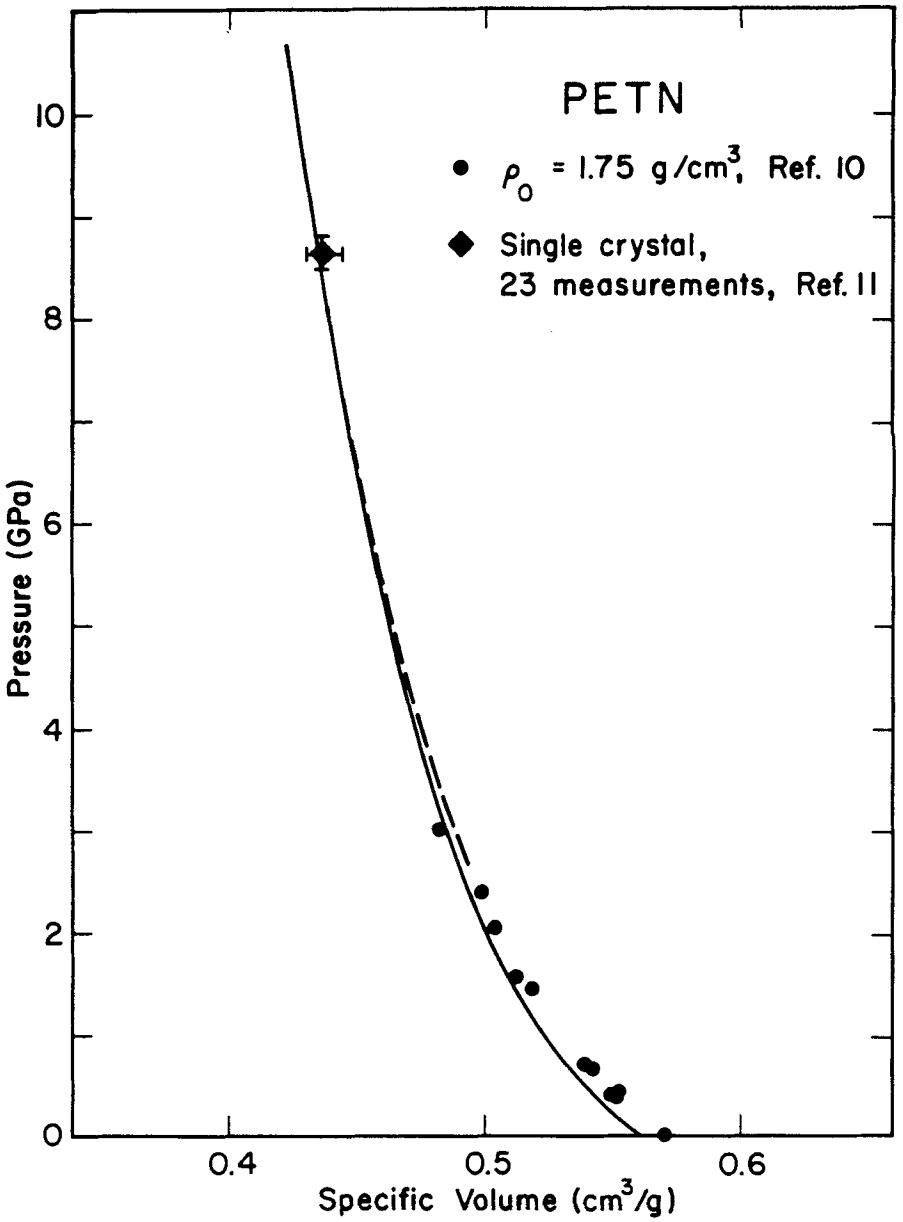

Figure 1

Pressure vs specific volume for PETN. The static Hugoniot curve (solid line) is from Ref. 8. The single crystal shock Hugoniot (dashed line) is from data summarized in Ref. 2.

overlaps the static curve quite well (Fig. 1). Halleck and Wackerle[12] showed that Hugoniot data below 4 GPa were indistinguishable for <110> and <001> orientations and apparently collapsed to the hydrostat. Los Alamos data on single crystal PETN are summarized in Ref. 2; data were taken by B. G. Craig, S. P. Marsh, and P. M. Halleck. For a shock velocity-particle velocity fit to the data I get $U = 2.74\ (\pm 0.06) + 1.81\ (\pm 0.06)\ u$ for $0.4 < u < 1.5$ mm/μs. This fit is shown as the dashed line in Fig. 1 and is nearly indistinguishable from the static curve.

Comparison for pressed, polycrystalline (PETN) can only be made to 3 GPa. There is a small pressure offset of about 0.2 GPa, but one cannot readily ascribe it to significant chemical energy release. At 2 GPa a 0.2 GPa offset would correspond to about 1 percent chemical energy release. For homogeneous single crystal PETN the static and shock compression curves are essentially indistinguishable to 10 GPa, and there is no apparent heat release due to explosive decomposition in the shock wave.

RDX

Olinger and coworkers' static pressure results on RDX show a phase transition between 4.0 and 4.8 GPa with a 1.6 percent volume decrease.[9] No shock data is available for pure RDX below 4 GPa, but data for PBX-9405-01[2] (RDX,3 wt% tris-(β-chloro-ethyl)-phosphate) are plotted in Fig. 2 for comparison with the static Hugoniot. As will be discussed in the TATB section, the specific volumes at a given stress level for pure RDX should lie at values about 0.004 cm^3/g larger than those

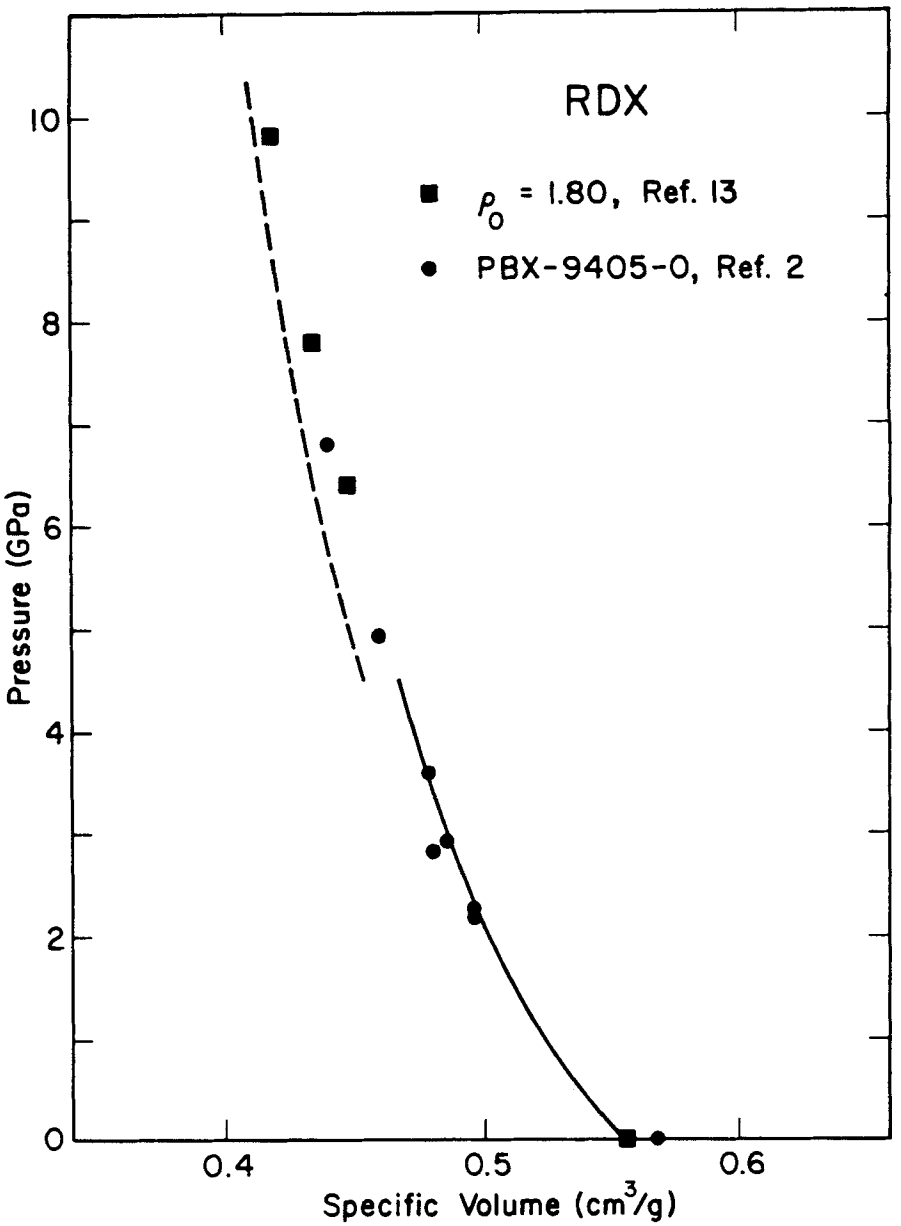

Figure 2

Pressure vs specific volume for RDX. The solid curve is for the static Hugoniot (Ref. 9). The dashed line is the isothermal curve for Phase III.

of the mixture. In that case the data for PBX-9405-01 agree very well with the static Hugoniot below 4 GPa, and there is no discernible evidence of chemical reaction.

From 4.5 to 10 GPa the static isotherm is plotted in Fig. 2. The Hugoniot would lie to the right of it, but its exact position cannot be calculated since the heat of transformation is not known.[9] The data for pure RDX[13] and for plastic-bonded RDX lie slightly to the right of the isotherm. They give no reason to suspect any large amount of exothermic decomposition of the explosive in the shock.

HMX

The static Hugoniot for β-HMX to 10 GPa obtained by Olinger and co-workers[9] is shown in Fig. 3. The wedge data of Craig[14] for 1.891 g/cm^3 pressed polycrystalline HMX are also displayed. The data have some scatter but agree fairly well with the static Hugoniot below 5 GPa. A point of concern is that the higher pressure points lie at slightly higher compressions than the static curve. Compression data for HMX to 50 GPa are shown in Fig. 4. Along with an extrapolation of the static Hugoniot, data for Craig's single crystal shots and his PBX-9404 work are shown.[14] PBX-9404 is a plastic-bonded HMX explosive with 3 wt% nitrocellulose and 3 wt% tris-(β-chloro-ethyl)-phosphate. The PBX-9404 snots were reanalyzed by the author.[15] The shock data indicate a material significantly more compressible at high stresses than extrapolation of the static Hugoniot would indicate. This is suggestive of a phase transition.

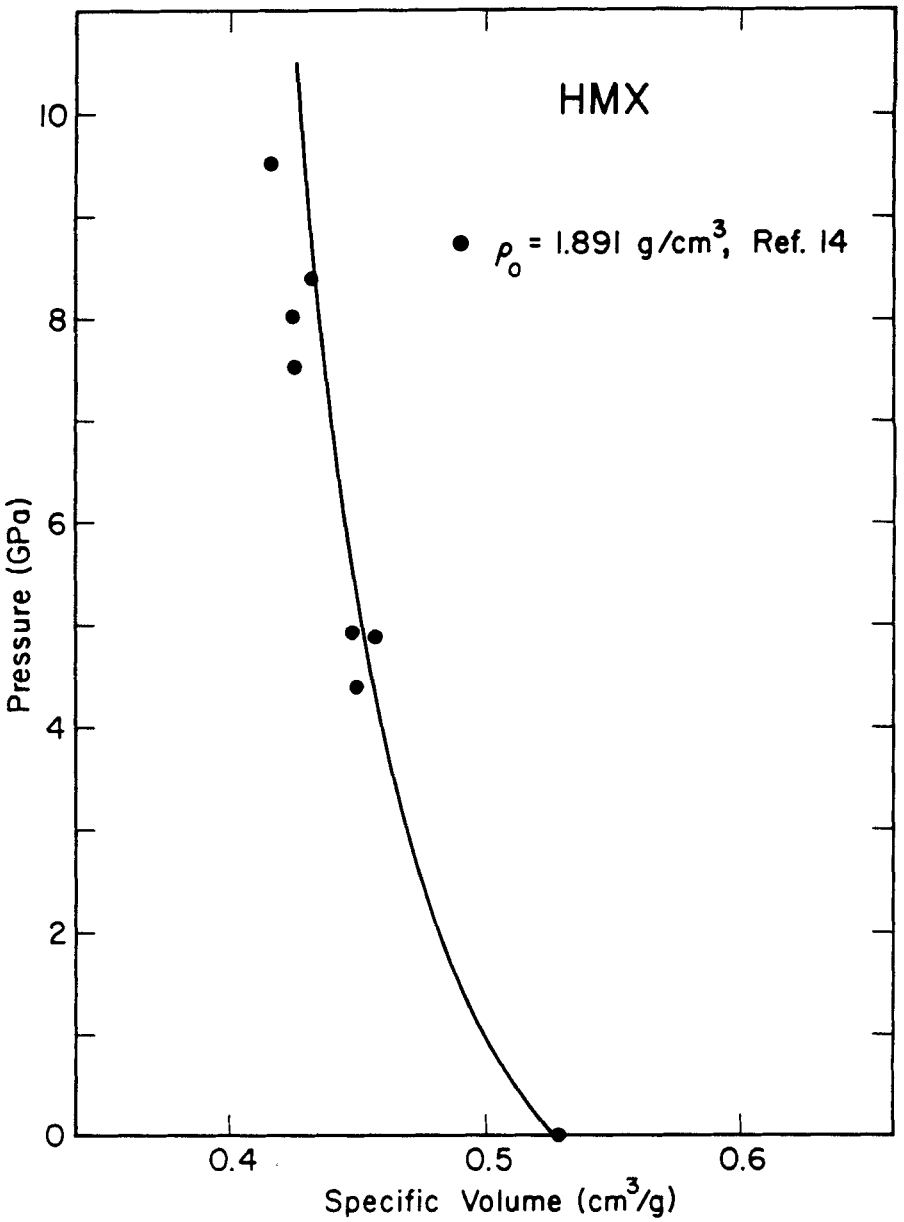

Figure 3

Pressure vs. specific volume for HMX to 10 GPa. The curve is the static Hugoniot of Ref. 9.

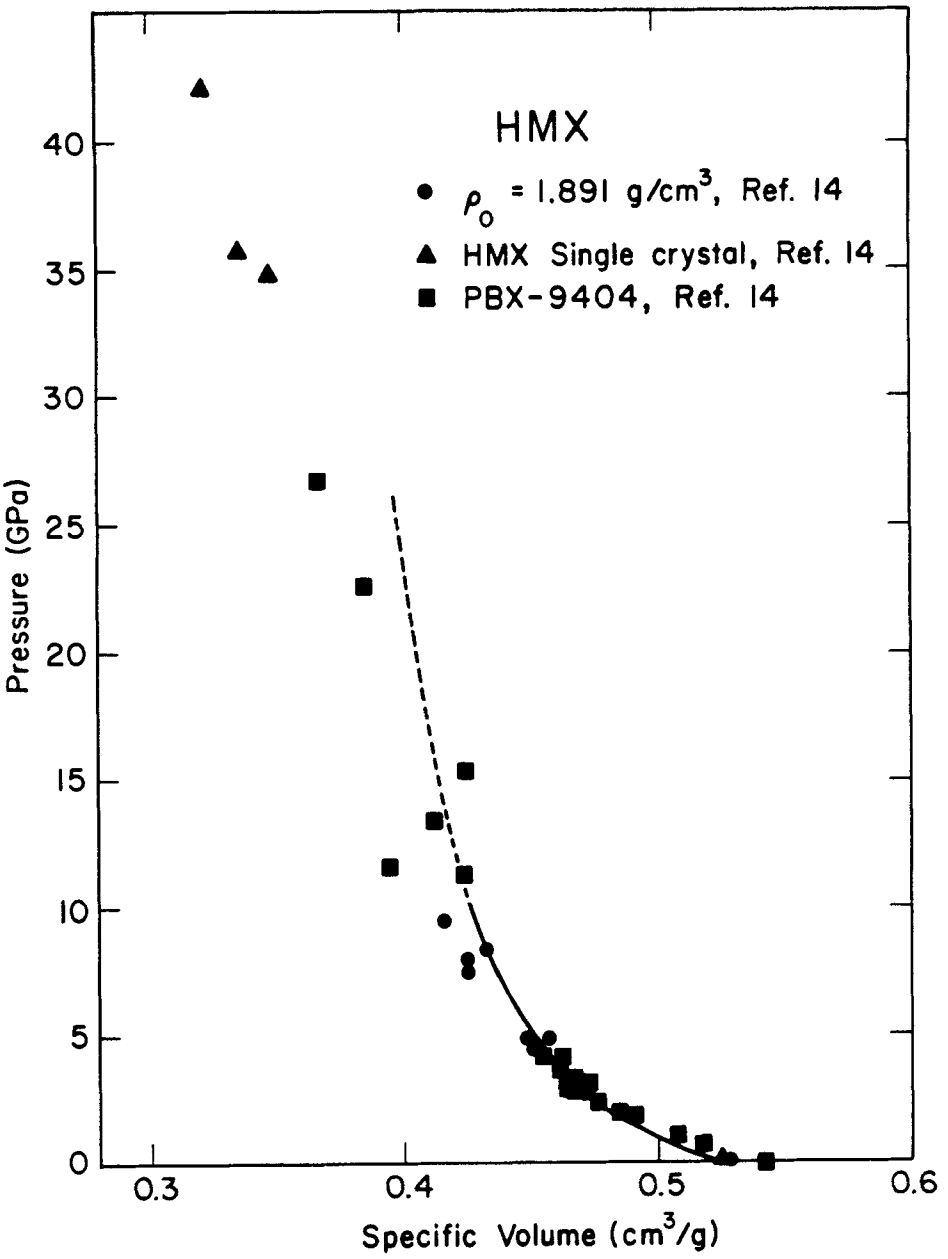

Figure 4

Pressure vs specific volume for HMX to 45 GPa. The curve is for the static Hugoniot (Ref. 9), extrapolated beyond 10 GPa.

TATB

The static Hugoniot to 7 GPa[8] is compared with wedge data for pure pressed, polycrystalline TATB in Fig. 5. Agreement is good over this common range. An attempt was made to extract the TATB Hugoniot from the PBX-9502 shock Hugoniot data[14,16] using the simple additive model. The Kel-F Hugoniot given in Ref. 2 was used; it has a density of 2.122 g/cm^3 compared to 2.02 g/cm^3 for Kel-F 800. This extracted TATB Hugoniot lies at about 0.004 cm^3/g greater specific volumes than the PBX-9502 curve for a given pressure. This puts it in very good agreement with the fit to the directly measured TATB Hugoniot data (Fig. 5). The TATB data (V_o = 0.541 cm^3/g) of Coleburn and Liddiard[4] agree fairly well with the results presented in Fig. 5. Overall they tend to lie at slightly larger specific volumes for a given pressure.

CONCLUSIONS

We see no significant pressure offset for any of the explosives studied. We thus conclude that shock wave data for these explosives obtained in wedge experiments, for example, determine the Hugoniot curves of the unreacted explosives. We also conclude for these explosives that the shock rise time is fast compared to the decomposition process in the pressure range studied. But further work is required to determine the validity of this conclusion about these rate processes at higher pressures.

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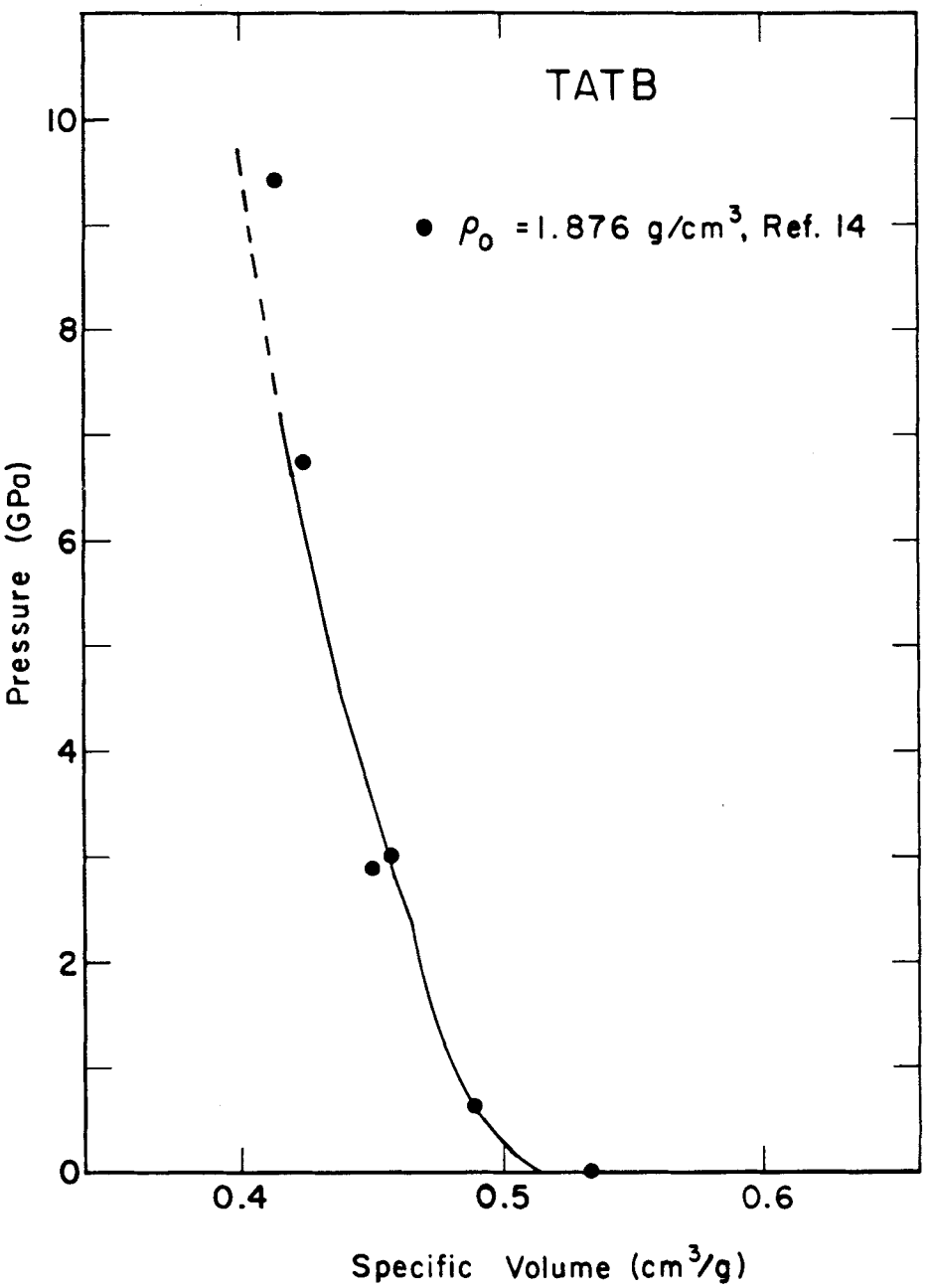

Figure 5

Pressure vs. specific volume for TATB. The curve for the static Hugoniot is from Ref. 8, extrapolated beyond 7 GPa.

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