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Shock Characterization of Diallyl Phthalate (DAP)

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Prepared by
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Shock Characterization of Diallyl Phthalate (DAP)

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Abstract

This study involved the shock characterization of Diallyl Phthalate (DAP), in particular, the equation of state as measured by the shock Hugoniot. Tests were done between 1 and 11 GPa impact shock pressure. The Hugoniot parameters were determined to be: ρ_o = 1.743, C_o = 2.20, and S = 2.33.

Acknowledgments

The author gratefully acknowledges the contributions of the following people without whose assistance this program would not have been possible. Don Hoke, 2513, whose interest in and application of DAP generated this program; John Matthews, 2514, who set up and operated the diagnostics; Mike Navarro, Ktech Corp., who operated the gas gun; Heidi Anderson, Ktech Corp., who built the projectiles and targets; and Lloyd Bonzon, 2514, who gave managerial support, direction, and encouragement.

Shock Characterization of Diallyl Phthalate (DAP)

Introduction

Diallyl Phthalate (DAP) is an unsaturated ester (di-allyl) of phthalic acid (phthalate), thus a member of the polyester family. This material has exceptional dimensional stability, excellent high heat and chemical resistance, is very tough and hard, has low moisture absorption, gives off virtually no volatiles during molding with a long shelf life and minimal shrinkage and has outstanding electrical properties; it is in particular a very good insulator. DAP is used extensively in the DOE complex as a potting material for small electrical devices. In explosive components, one application is as a "header" material for explosive ignitors, the section which incorporates the bridgewire and posts. In the past, when a material model was needed in a code which assisted in the design of a component, the values for an analogous plastic, polymethylmethacrylate (PMMA) were substituted. The present study was initiated to measure the Hugoniot values for DAP and to compare its shock Hugoniot with that for PMMA.

Experimental Procedure

DAP Materials

"Hockey pucks" of 5.08-cm (2 in.) diameter and 6.27-mm (0.5 in.) thickness were molded individually and then machined to the desired dimensions.

Gas Gun

The light-gas gun system used is described in detail in Reference 1. Briefly, the barrel is 9 m long, with an inside diameter of 63.4 mm. The breech is of a quick-acting, quick-change design with two inserts; the first is a "wrap-around" for low-velocity shots utilizing nitrogen (below 0.5 km/s) and the second is a "dual-diaphragm" for higher-velocity shots using helium (up to 1.5 km/s for projectiles with weights below 0.2 kg).

VISAR

One modern technique used for measurement of shock phenomena is the VISAR (Velocity Interferometer System for Any Reflector)[2]. A "Push-Pull" VISAR method developed by Hemsing[3] and used in these experiments results in effective cancellation of light intensity changes during the measurement. In addition, the return laser light is divided between two legs (dual-leg) with different calibration factors to insure the proper measurement of shock jump.

Projectiles/Targets for Hugoniot Measurements

A schematic of the projectile/target configuration is shown in Figure 1. DAP specimens were mounted on the front of either nylon/foam or aluminum sabots. The specimens acted as flyer plates in impacts with the target materials. The target materials of either polymethyl methacrylate (Polycast), or quartz, or sapphire had known Hugoniot relationships. (Polycast is the currently available version of PMMA whose Hugoniot relationship was recently determined by Matthews and Weirick[4] and was found to be experimentally identical to PMMA.) The targets consisted of both a thin, 1-mm buffer plate and thicker, 12.7-mm window of the same material. The window had a 0.1-μm thick layer of vapor-deposited-aluminum on the front which reflected the laser beam for the VISAR.

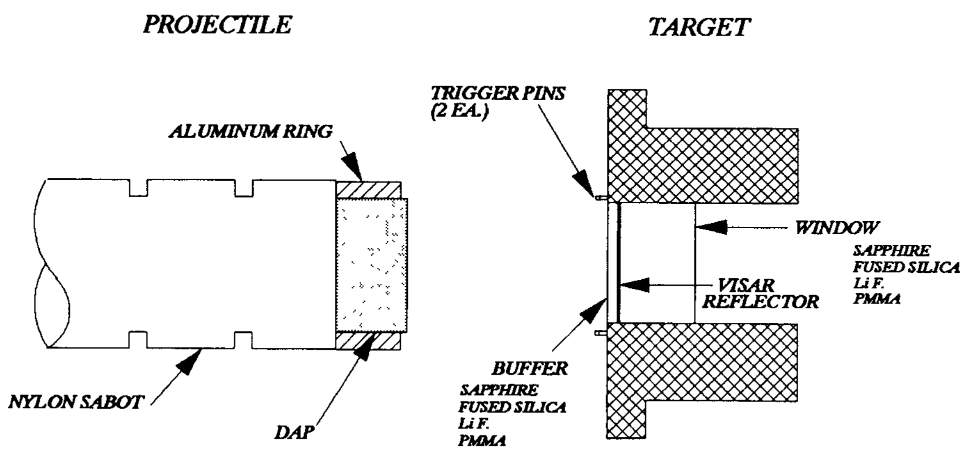

Figure 1. Schematic of Projectile/Target Configuration

Hugoniot Results

Specifics of shot conditions for the Hugoniot tests on the DAP are given in Table 1. These include the shot number, the target (buffer and window) material, and the measured projectile velocity. Plots of measured particle velocity in the targets versus time are given in Figures 2 through 5. A summary of the test results is also given in Table 1. These include the particle velocity measured in the target, the particle velocity in the DAP calculated from that measured in the target, the pressure in the DAP calculated from the impact conditions and the known Hugoniot values for the target materials[5], and the shock velocity in the DAP calculated using the following equation:

$$U_s = P/\rho_0 U_p \ , \quad (1)$$

where U_s is the shock velocity, P is the impact pressure, ρ_0 is the initial density, and U_p is the particle velocity.

Table 1. Test Conditions and Results

Shot No.	Target Materials	Projectile Velocity (km/s)	Impact Pressure (GPa)	Particle Velocity Target (mm/μs)	Particle Velocity DAP (mm/μs)	Shock Velocity (mm/μs)
385	PMMA	0.547	1.126	0.31	0.237	2.72
386	PMMA	0.941	2.136	0.53	0.411	2.98
387	PMMA	1.279	3.267	0.74	0.539	3.48
388	Fus. Si.	1.060	4.534	0.395	0.665	3.91
389	Fus. Si.	1.264	5.164	0.49	0.774	4.16
390	Fus. Si.	1.420	6.413	0.56	0.860	4.28
394	LiF	1.417	7.178	0.47	0.947	4.35
410	Sapphire	1.296	8.93	0.195	1.101	4.65
401	Sapphire	1.420	10.300	0.225	1.195	4.95

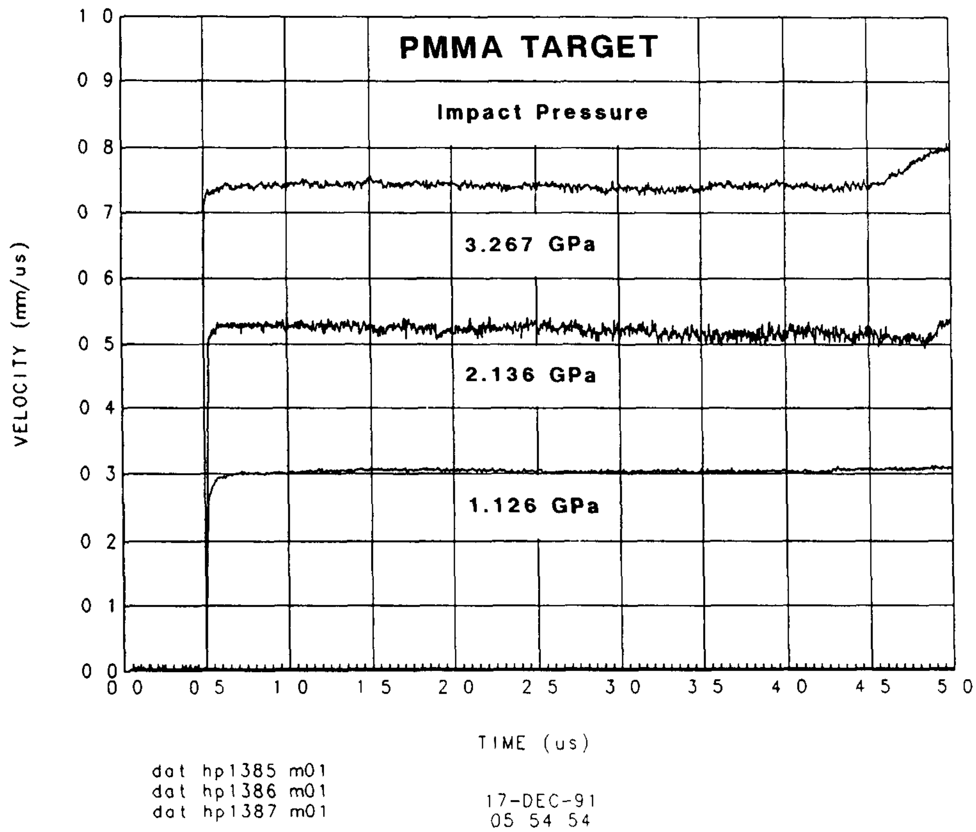

Figure 2. Measured Particle Velocity in PMMA After Impact With DAP at Various Impact Pressures

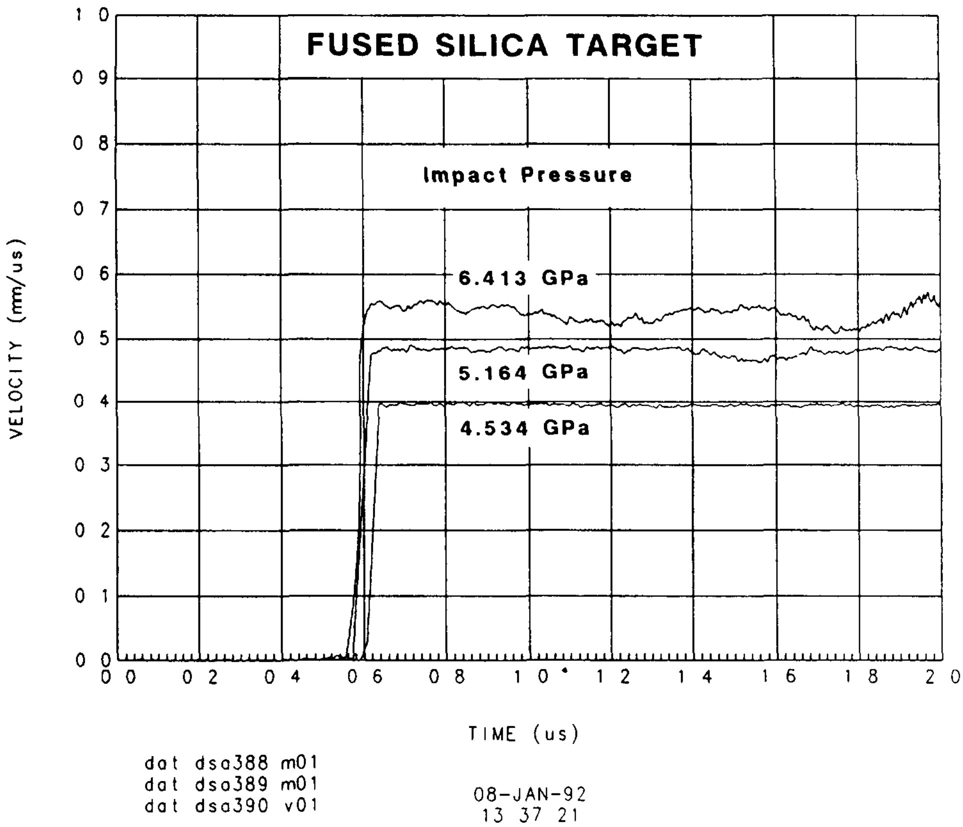

Figure 3. Measured Particle Velocities in Fused Silica After Impact With DAP at Various Impact Pressures

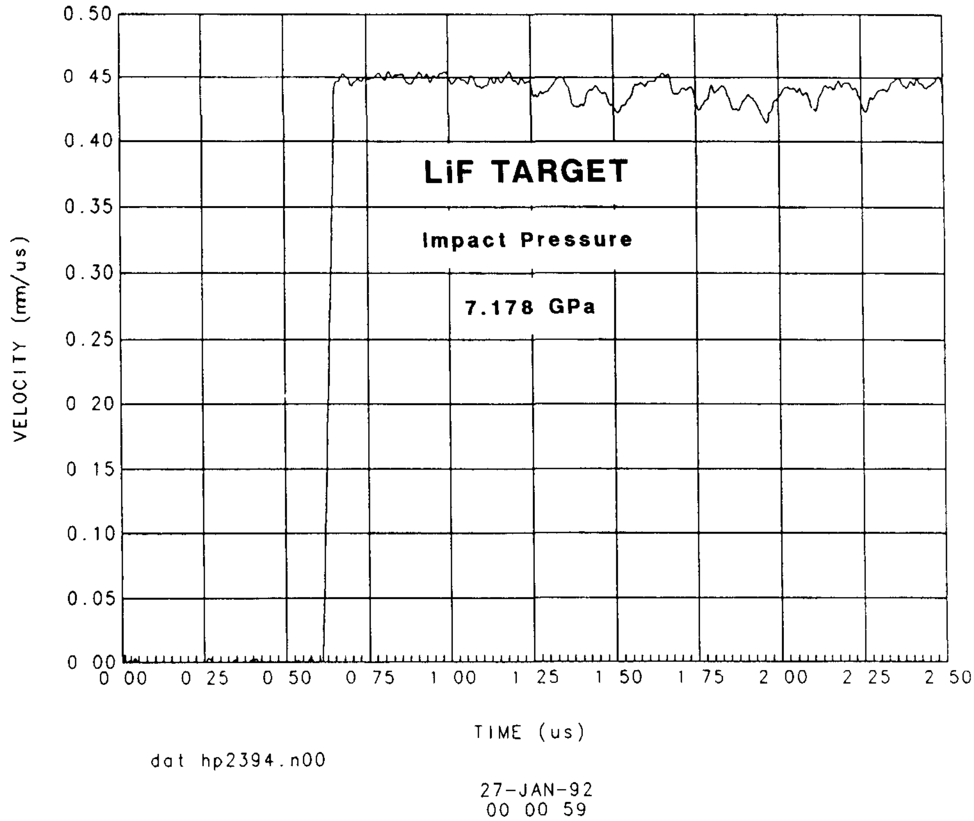

Figure 4. Measured Particle Velocity in Lithium Fluoride After Impact With DAP

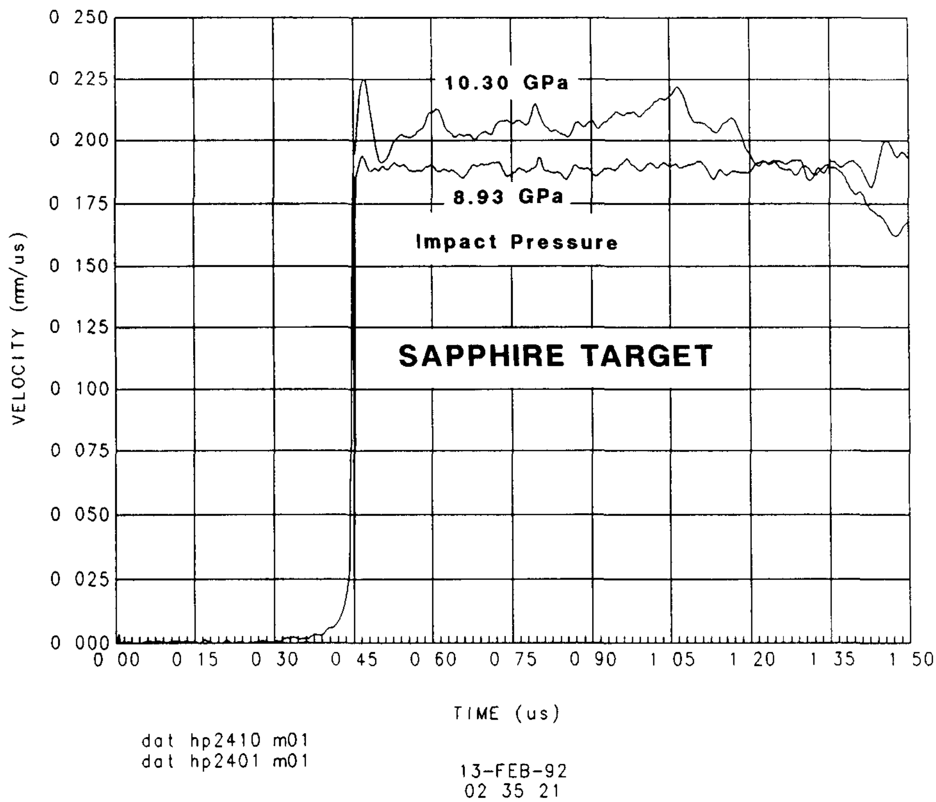

Figure 5. Measured Particle Velocities in Sapphire After Impact With DAP at Various Impact Pressures

The relationship of pressure as a function of particle velocity for the DAP material is given in Figure 6. Figure 7 gives the shock Hugoniot for DAP as the particle velocity versus shock velocity. In the shock Hugoniot equation:

$$U_s = C_o + S\,U_p\ , \qquad \textbf{(2)}$$

where C_o is the intercept which should equal the bulk sound velocity and S is the slope. The equation can be used in conjunction with the data plotted in Figure 6 to calculate C_o and S. The values for DAP were determined to be $C_o = 2.20$ and $S = 2.33$.

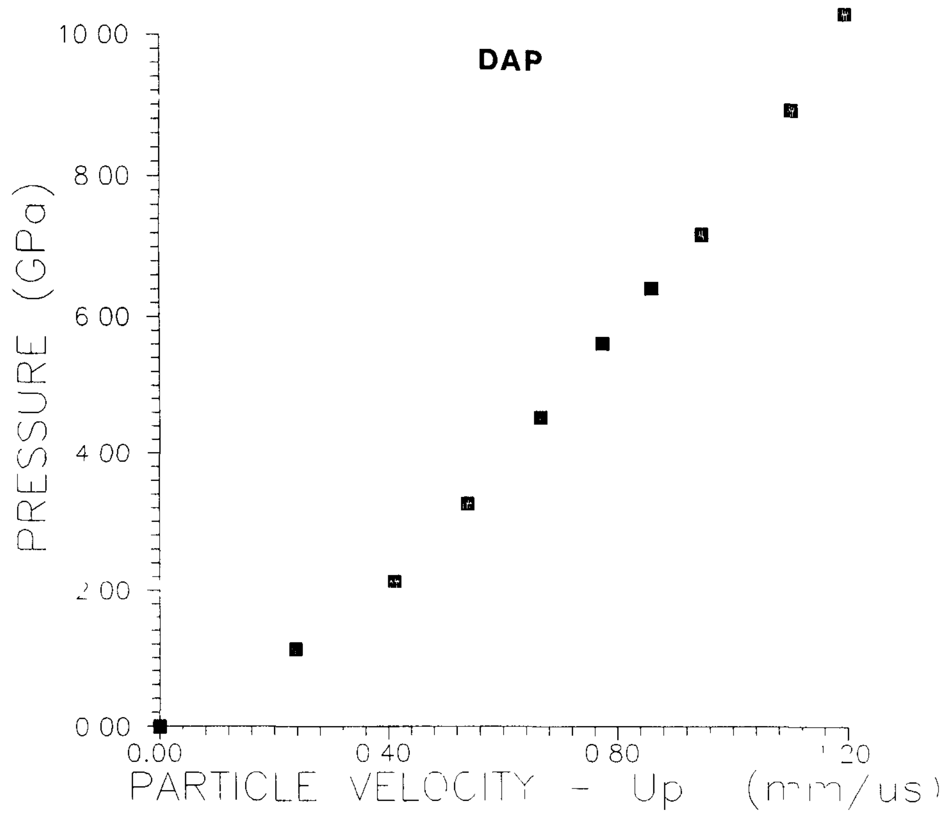

Figure 6. Plot of Pressure as a Function of Particle Velocity for DAP

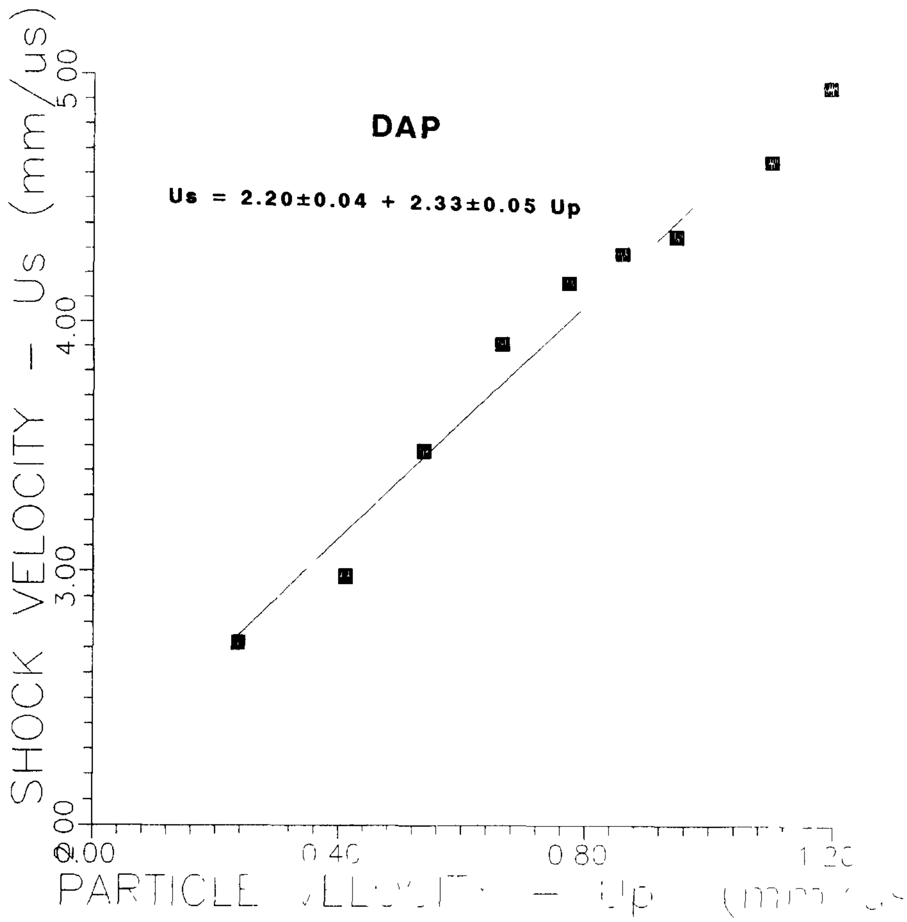

Figure 7. Shock Hugoniot for DAP

Discussion

The relationship of pressure as a function of particle velocity for DAP as compared to PMMA is shown in Figure 8. It can be seen that the two materials would show an appreciably different response to the same impact stimulus. The DAP has a significantly lower particle velocity than PMMA for a given impact pressure. Analogously, these differences are also shown in the comparison of shock Hugoniots shown in Figure 9. DAP has a higher shock impedance ($\rho_0 \times U_p$) than PMMA.

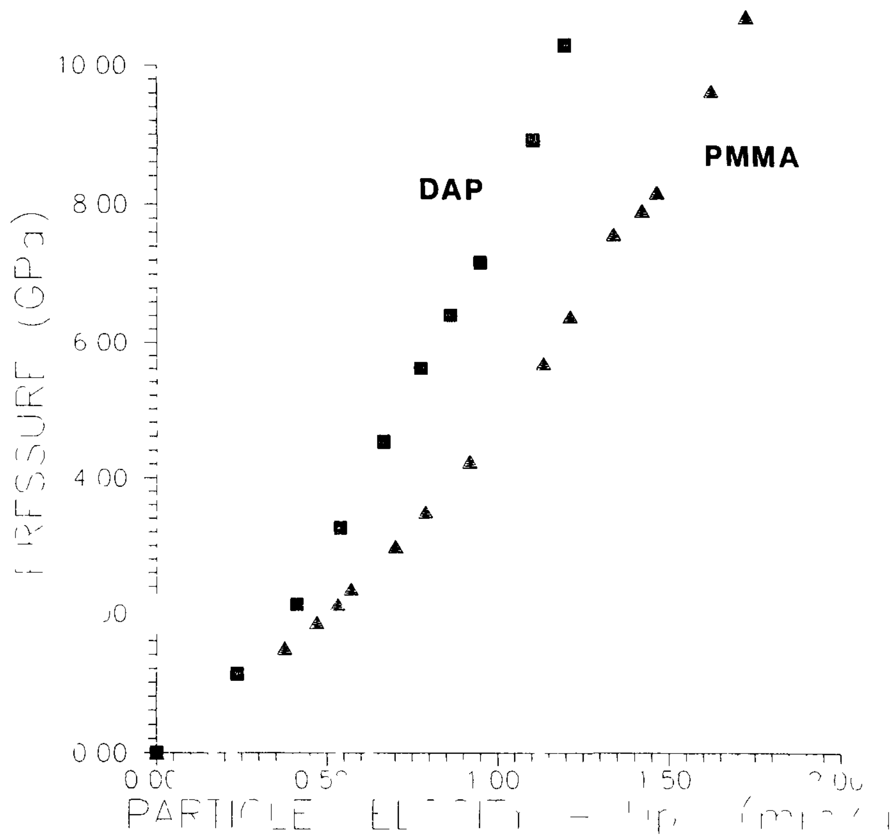

Figure 8. Comparison of DAP and PMMA in Pressure-Particle Velocity Space

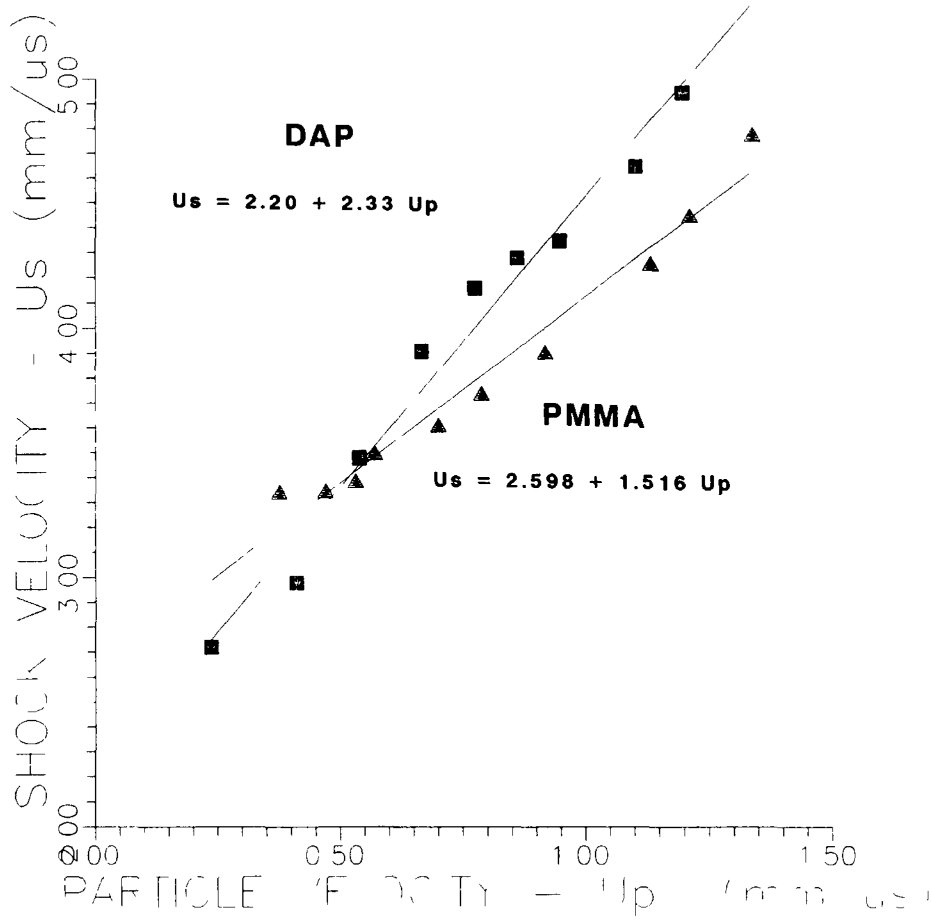

Figure 9. Comparison of DAP and PMMA Shock Hugoniots

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