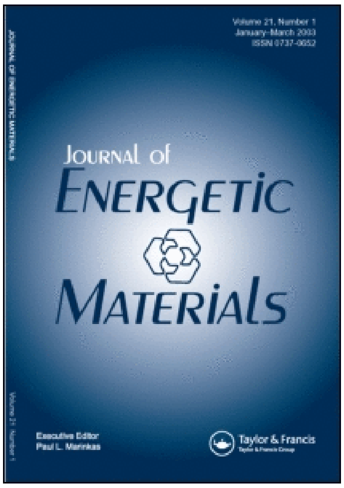

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SHORT PULSE INITIATION OF A PLASTIC-BONDED TATB EXPLOSIVE

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ABSTRACT

Short-pulse initiation experiments were done on PBX 9502 using explosively driven magnesium flyer plates of thicknesses from 0.5 to 2.0 mm. Input pressure was 13.1 GPa. Magnesium is a good impedance match to PBX 9502 so the input pulses were clean and sharp. In-material particle velocity histories were obtained using the axisymmetric magnetic probe, and shock trajectories were measured using the wedge technique. For 0.5 and 1.0-mm-thick flyers no initiation of detonation was observed. For 2-mm-thick flyers giving a pulse duration of about twice the steady reaction zone time a run to detonation of 11.8 ± 1.1 mm was measured; this is 50% longer than the run for a sustained shock for the same input pressure.

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INTRODUCTION

Short pulse shock initiation of explosives has been used for some time as an adjunct to sustained shock initiation.[1-7] Short pulses provide more stringent tests of numerical modeling of reactive flow.[3] They also show particle size effects in cases where sustained shocks do not.[5] In a practical sense a short pulse is more akin to the type of pulse a piece of explosive receives from a detonator/booster assembly. One would also like to answer the question, "how short is short?" That is, at what pulse length does the run to detonation become significantly extended beyond that found for a sustained shock?

In order to answer this question, I wanted to have as clean a short pulse as possible. This means using a flyer plate of the same shock impedance as the explosive. Then the wave input will be nearly square with a steep rarefaction to near zero pressure as will be shown in Fig. 5. Otherwise for a high-impedance flyer plate the relief to zero pressure will be achieved by a series of reverberations.[6]

A plastic-bonded TATB (triamino trinitrobenzene) explosive PBX 9502, an insensitive explosive, was studied; by weight it contains five percent Kel-F plastic (polytrifluorochloroethylene). It has a large reaction zone length of several millimeters and a reaction time of 0.25 to 0.4 μs.[8,9,10] This gives one the opportunity of making time-resolved measurements of plane shock initiation of explosive in a case where the initiating pulse length is comparable to the steady reaction time, a different regime than has been studied previously.

Flyer plates of AZ31B magnesium alloy were used since it is a good shock impedance match to PBX 9502 (Fig. 1). Tests were done for flyer thicknesses of 0.5, 1.0, 1.6, and 2.0 mm; these gave shock pulse lengths of 0.135, 0.271, 0.433, and 0.541 μs, respectively. Shock trajectories were measured in wedge experiments using 30-mm-thick wedges, and in-material particle velocity histories were obtained using the axisymmetric magnetic (ASM) probe.

The flyer plates were propelled at 2.53 mm/μs using an explosively driven, impedance-mismatch system. This velocity generated a pressure of 13.1 GPa at the impact face. Run to detonation is 7.8 mm for a sustained shock of this strength,[5] and time to detonation is 1.4 μs. For flyer plates 0.5 and 1.0 mm thick only shock attenuation was observed in the sample. For a 1.6-mm-thick flyer plate, run to detonation was about 26 mm whereas for a 2-mm-thick flyer the run was about 12 mm. Both of these distances are significantly longer than the sustained-shock distance of 7.8 mm. Both the amount of attenuation for 0.5-mm and 1.0-mm flyer plates and the extended runs for 1.6-mm and 2.0-mm flyer plates were unexpected in terms of the question of how short is short. Preliminary numerical modeling of these experiments using a DAGMAR rate[3] which successfully replicated the sustained-shock sensitivity (the Pop plot) did not predict these results. Also, a $P^2\tau$ rule based on results for electrically driven plastic flyer plates[7] used to design the experiments proved to be incorrect. Results for high-impedance steel plates driven by PMMA[5] also did not give the correct guidance. This all says that in addition to pulse duration and shock strength, details of the shock pulse shape and the flyer plate condition are important.

In-material particle velocity histories using the ASM probe were obtained for flyer plates of 0.5 and 2.0 mm thickness. The attenuating wave profiles for the 0.5-mm flyer plates were fairly well simulated by a hydrocode calculation treating the explosive as inert. Inert behavior is somewhat surprising for a 13.1 GPa shock. For the 2.0 mm flyer plate shots, the pulse shapes but not the extended run were fairly well simulated in a hydrocode run with a DAGMAR rate law.

EXPERIMENTAL TECHNIQUE

The main experimental arrangement is shown in Fig. 2. A 203-mm-diam plane-wave lens was used to initiate a 102-mm-thick layer of PBX 9501 (95 wt% HMX with an Estane binder). The thick layer of explosive was chosen in order to reduce the steepness of the Taylor wave so as to minimize the opportunity for spall in the flyer plate. The stainless steel was relatively thick (19 mm) to further reduce the steepness of the rarefaction. The flyer plate pops off the steel plate because of the impedance mismatch and flies across an evacuated gap (typically 16 mm) before impacting the test explosive. It was checked by hydrocode calculation that the steel plate arrival at the target was late enough so that it did not affect the initiation history. Explosive sample pieces were 91 mm in diameter and the rear piece was usually 12.5 mm thick.

In-material particle velocity histories were obtained using the ASM probe.[11,12] The motion transducer was a 0.075-mm-thick 1100 aluminum foil (130 mm diam) embedded in the PBX 9502 with Aralhex glue (polyol-cured polyurethane). The interaction between the moving foil and the magnetic flux lines from the permanent magnet (a 12.7-mm by 12.7-mm cylinder of INDOX-5) induces a voltage in the pickup coil. Voltages were recorded in a balanced mode using a coaxial cable on each output leg of the coil fed to 7A13 differential amplifiers in Tektronix 7612D 5-ns-sampling rate digitizers. The pickup coil was 38.1 mm in diameter and about 14 mm from the foil. This means that the area of the foil sampled by the coil is about 65 mm in diameter; this places a limit on signal rise time due to possible nonsimultaneity of the shock wave over such a large area. The advantage of the technique is that there are no leads to attach to the embedded transducer so that it is able to withstand severe environments; the pickup coil is outside the shocked, reacting explosive. For a 0.075-mm-thick aluminum foil, the field of the permanent magnet can diffuse through the moving foil during the time of the experiment. For these foils, a recession velocity for the magnetic field images of 0.6 mm/μs was used.[11] The computed particle velocity histories are not very sensitive to the value used for the recession velocity. Doubling the recession velocity increased the particle velocity by 0.01 mm/μs at the shock and by 0.05 mm/μs at the end of the rarefaction. In these experiments, there was some ramping voltage signal recorded before the shock arrived at the foil and set it in motion. In some way the pickup coil was sensing the flyer plate motion. This presignal was subtracted from the recorded voltage before it was converted to particle velocity.

A major concern in the experiments was accelerating the magnesium flyer plates without spall or loss of flatness and lateral integrity. A number of shots were done to check flyer planarity and lateral integrity. In three shots streak camera records of flyer planarity at impact were obtained; measured nonsimultaneity was 16, 40, and 86 ns across a 100 mm diameter. The flyer plate thicknesses were 2, 3, and 1 mm, respectively. These shots also demonstrated that the flyer plate was maintaining its lateral integrity and not fragmenting. In addition, the motion of the flyer plate was monitored with the ASM probe for shots with plate thickness of 0.5 and 2.0 mm. The particle velocity history for a 0.5-mm-thick flyer plate is shown in Fig. 3. The shot was done with an uncalibrated magnet so the data have limited accuracy in particle velocity. But one can see clearly the effect of the wave reverberation in the plate as it flies across the gap. For this 0.5-mm-thick plate the reverberation time is 0.143 ± 0.014 μs; this is 87% of the round trip time of 0.164 μs calculated for a longitudinal sound wave at zero pressure indicating that no large spall occurred. For a 2-mm-thick plate the measured reverberation time was 0.70 ± 0.03 μs, which is 107% of the time for a sound wave round trip (0.656μs) again indicating the absence of spall.

Velocity of the flyer plates was measured on two shots using four piezoelectric pins. For a 0.5-mm-thick flyer, a velocity of 2.52 ± 0.03 mm/μs was measured; for a 2-mm-thick flyer, 2.53 ± 0.07 mm/μs was obtained. The wedge experiments were done in the manner described in Ref. 13. In all experiments the samples were held at a temperature of 23 ± 2^oC.

The PBX 9502 explosive used was Blend 79-04 which has been used in many characterization experiments at Los Alamos. It has a large amount of fine particles with more than 25 wt% less than 10 microns. The particle size distribution is given in Ref. 5 (Sample 3). Chlorine content of the TATB powder was 0.53 wt%.

EXPERIMENTAL RESULTS

The first ASM shots in this material were done with 0.5 mm flyer plates. The thinner plates reduce the chance of spall. Furthermore, W. L. Seitz showed that extended run to detonation occurs in PBX 9502 at 16 GPa for a 0.4-mm-thick stainless steel plate pushed by PMMA.[5] The particle velocity histories measured in the current work at 3, 6, and 9 mm depths are shown in Fig. 4. Only attenuation is seen; there is no evidence of reactive buildup. It is true that 13.1 GPa is below the GO threshold line for electrically driven plastic flyer plates of the same pulse duration on another plastic-bonded TATB explosive RX03BB.[7] In fact, my results are in modest agreement with a one-dimensional hydrocode simulation of the experiment treating the explosive as inert (Fig. 5). Even though no initiation of detonation was seen, the data taken nevertheless demonstrate that good quality particle velocity profiles may be obtained in explosive with this technique.

Next, a wedge experiment was done for a 1-mm-thick flyer plate. Again, only attenuation was seen in the shock trajectory; the shock speed decreased from 5.3 mm/μs to 3.3 mm/μs in 25 mm of run. A subsequent experiment with a 1.6 mm flyer, however, gave evidence of transition to detonation after 26 mm of run.

The final series was done with 2-mm-thick flyers. Two wedge experiments were done; the measured runs to detonation were 11.0 and 12.5 mm. This is an extended length of run (50% longer) compared to the sustained shock run of 7.8 mm. One such record is shown in Fig. 6. This result is similar to that reported for LX-17 (92.5 wt% TATB, 7.5 wt% Kel-F) where a 12-GPa input shock of 0.6 μs duration was generated by a high-impedance ceramic flyer plate. There a run of 16 mm was observed where the sustained shock run was 13 mm.[14] Particle velocity profiles obtained by the ASM probe at 3, 6, 8, and 11 mm depths are shown in Fig. 7. C-J particle velocity is about 1.9 mm/μs and spike particle velocity about 2.6 mm/μs. The prompt character of the initiation can be seen for this case where the pulse length was about twice the steady-reaction-zone-time. The shock strengths are compared to the wedge result in Fig. 6 using the inert Hugoniot $U = 2.36 + 2.23u$ to get shock speed U from peak particle speed u. The ASM probe values are generally higher. An attempt was made to get an ASM probe record in the detonation regime, 15 mm deep. The voltages obtained were anomalously low. This could have been caused by fragmentation of the foil by the detonation or by the conductive layer of detonation products between the sensing coil and the foil. Some of the effect may already be apparent in the record at 11 mm (Figs. 6 and 7); comparison to the wedge record suggests that more growth occurred than was measured at 11 mm by the particle velocity record. It may also be worth noting the increasing rise time as the transition is approached.

DISCUSSION

It is worth examining in more detail the differences and similarities between the experiments with magnesium and stainless steel flyers. It turns out that pulse duration is about the same for 0.5 mm magnesium and 0.4 mm stainless steel (Table 1); by pulse duration we mean the time between impact and the arrival of the leading edge of the rarefaction at the flyer/sample interface. Only attenuation was observed for magnesium at 0.5 mm and 1 mm and 13 GPa, whereas the 0.4 mm steel plate at 16 GPa gave detonation with a run more than twice as long as for a sustained shock. This suggests that more than pulse duration is involved.

TABLE 1
Short Pulse Initiation Results

Flyer Type	Thickness (mm)	Pulse Length (μs)	Input Pressure (GPa)	Run to Detonation (mm)
AZ31B Magnesium	0.5	0.135	13.1	–
	1.0	0.271	13.1	–
	1.6	0.433	13.1	26
	2.0	0.541	13.1	12
	Thick	Long	13.1	7.8
304Stainless Steel (Ref. 5)	0.4	0.134	16.4	8.2
	Thick	Long	16.4	3.8

The flyer kinetic energy is 5.7 MJ/m^2 for the 1 mm magnesium flyer and 5.5 MJ/m^2 for the 0.4 mm steel. Based on a critical kinetic energy criterion the magnesium flyer should cause initiation if the steel one does. In addition these values are much less than the threshold kinetic energy of over 10 MJ/m^2 at 16 GPa for plastic flyers.[15] Thus a critical energy criterion does not explain the results.

$P^2\tau$ also appears inadequate in explaining the results. The $P^2\tau$ value for a 1 mm magnesium flyer is higher than that for the 0.4 mm steel plate so the magnesium flyer impact should lead to detonation if the steel flyer does. In E. F. Gittings work on detached aluminum flyers impacting PBX 9404, she found that if the duration of the shock pulse was greater than 0.3 of the time to detonation for a sustained shock, then the run to detonation was the same as for a sustained shock.[1] For 13 GPa shocks in PBX 9502 there is an extended run (0.6 μs longer) even where the ratio of pulse duration to time to detonation is 0.38.

One must consider details of the experiments. Because the impedance mismatch of the steel plate leads to a pressure ringdown in the rarefaction wave, there is a greater total impulse for a given pulse duration as defined above. The PMMA pushing the steel plate also may contribute to the impulse in a significant way. Additionally the steel plate provides greater inertial confinement for the initial decomposition near the impact face; a 0.4 mm steel plate has 3.5 times more mass per unit area than a 0.5 mm magnesium plate. Greater confinement will tend to keep the pressure and density up while decomposition is taking place, in turn enhancing the rate and extent of decomposition. It is also true that the decomposition rate is probably several times larger at 16 GPa than at 13 GPa.[16] All of these details in concert are probably adequate to explain the different results for the magnesium flyers and the driven steel plate as well as previous work with aluminum and plastic flyers.

CONCLUSIONS

I was able to obtain a great deal of information about the nature of the initiation of an insensitive explosive by short pulses generated by a flyer plate impedance-matched to the PBX 9502. In-material particle velocity histories were measured for two magnesium flyer plate thicknesses. Comparison with results in Ref. 5 for stainless steel plates driven by PMMA (Fig. 8) shows that the nature of the flyer plate as well as the nature of the total loading and unloading profile matter and not just the time before rarefaction begins. The importance of the nature of the unloading history was noted previously.[6] For a strong, fairly long pulse of 13.1 GPa and 0.54 μs (2 mm Mg flyer) we still see an extended run to detonation.

These short pulse data for shock initiation provide a stringent test for numerical modeling of shock initiation of detonation using global rate prescriptions. My preliminary numerical modeling with a hydrocode did not simulate an extended run for such a thick pulse. This behavior in insensitive explosives with long reaction times requires modification of our decomposition rate modeling beyond what has worked for other regimes and explosives.[17]

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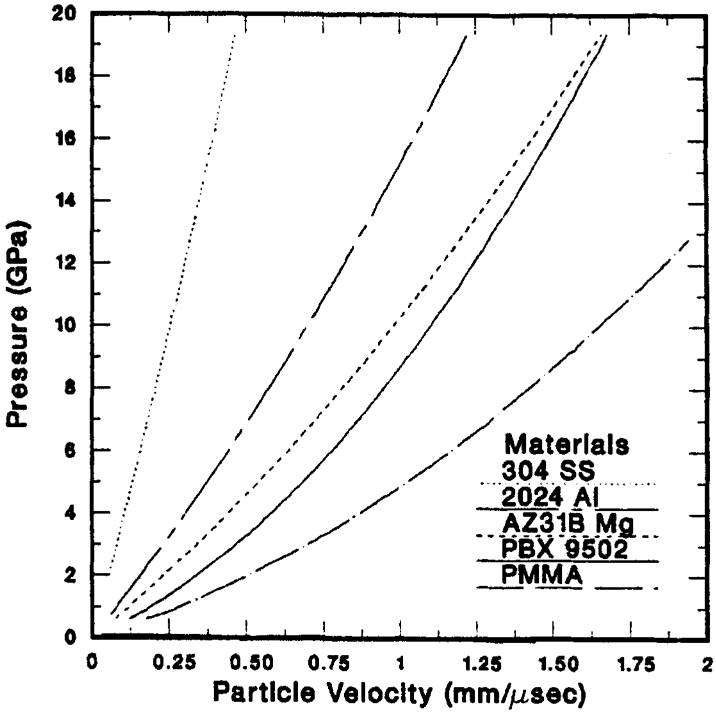

FIGURE 1

Pressure vs particle velocity plot showing the good match between AZ31B magnesium alloy and PBX 9502.

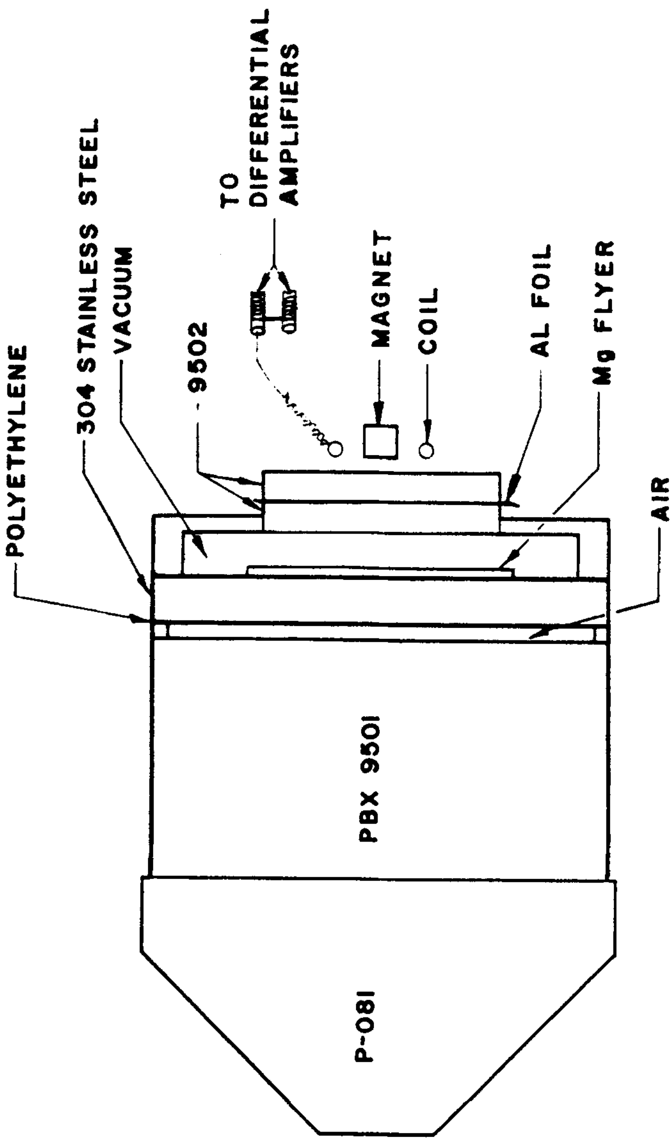

FIGURE 2

Experimental arrangement for recording in-material particle velocity histories during flyer plate initiation of an explosive.

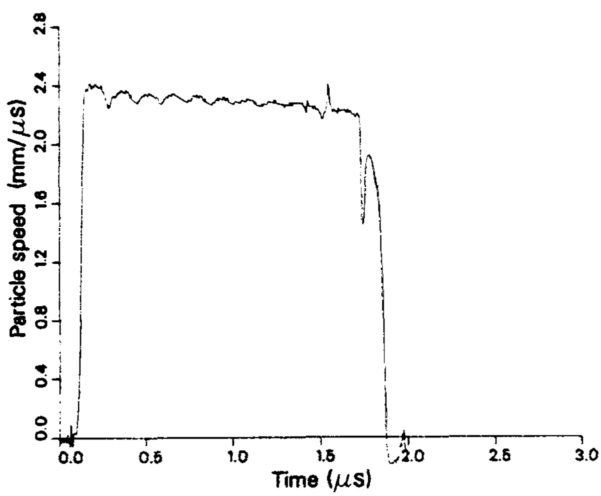

FIGURE 3

Velocity history of the front face of the magnesium flyer plate as it crossed the evacuated gap between the stainless steel and the explosive. The dips in the velocity are due to the waves reverberating in the flying plate. The gap for this shot was only 4.2 mm.

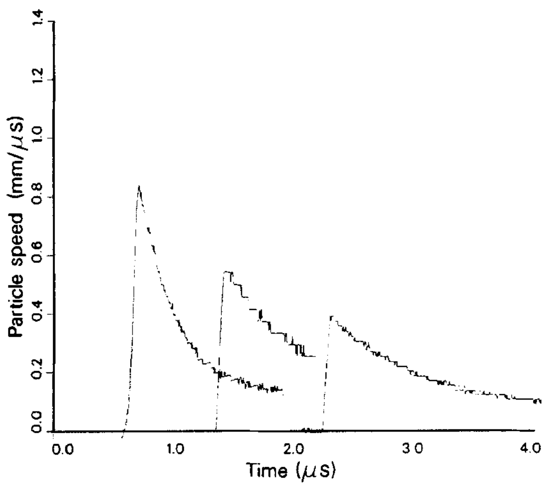

FIGURE 4

In-material particle velocity histories at 3, 6, and 9 mm depths in PBX 9502 impacted by a 0.5-mm-thick magnesium flyer plate moving 2.53 mm/μs. Initial pressure is 13.1 GPa and initial particle velocity was 1.31 mm/μs.

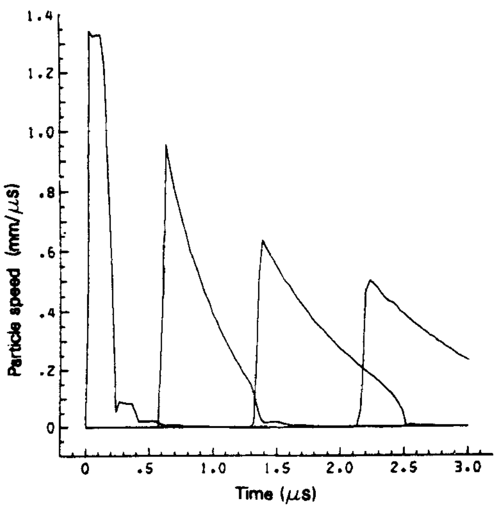

FIGURE 5

Particle velocity histories in PBX 9502 at 0, 3, 6, and 9 mm depths for the experiments shown in Fig. 4 from a hydrocode simulation treating the explosive as inert.

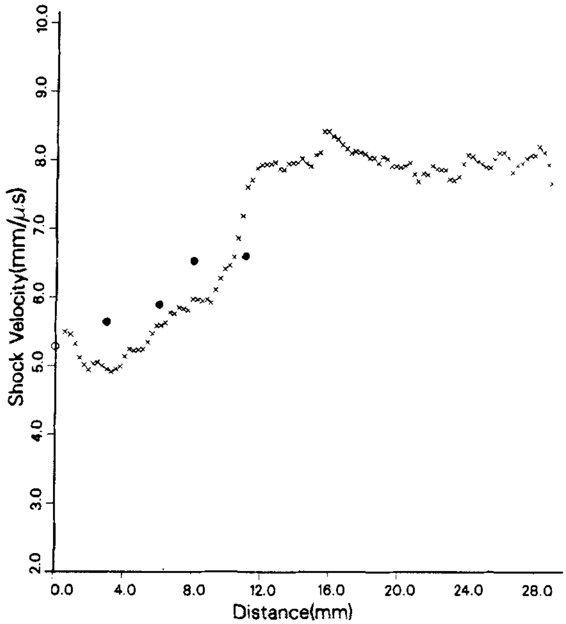

FIGURE 6

Wedge record of the shock trajectory shown as shock velocity vs distance for a 2-mm-thick magnesium flyer plate moving 2.53 mm/μs. Initial pressure is 13.1 GPa. Shock speeds calculated from the ASM probe records are shown as circles.

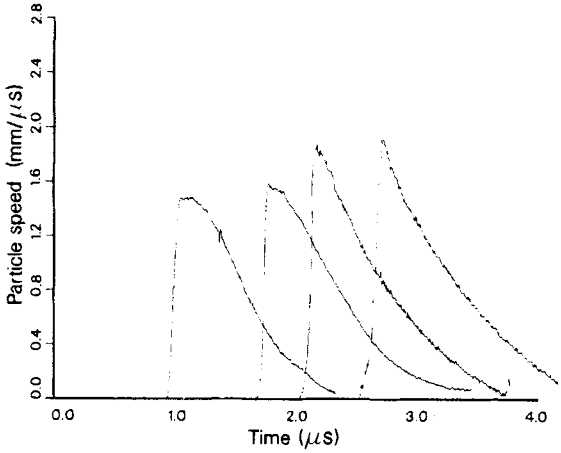

FIGURE 7

In-material particle velocity histories for PBX 9502 impacted by a 2.0-mm-thick magnesium flyer plate moving 2.53 mm/μs. Initial pressure is 13.1 GPa and initial particle velocity is 1.31 mm/μs.

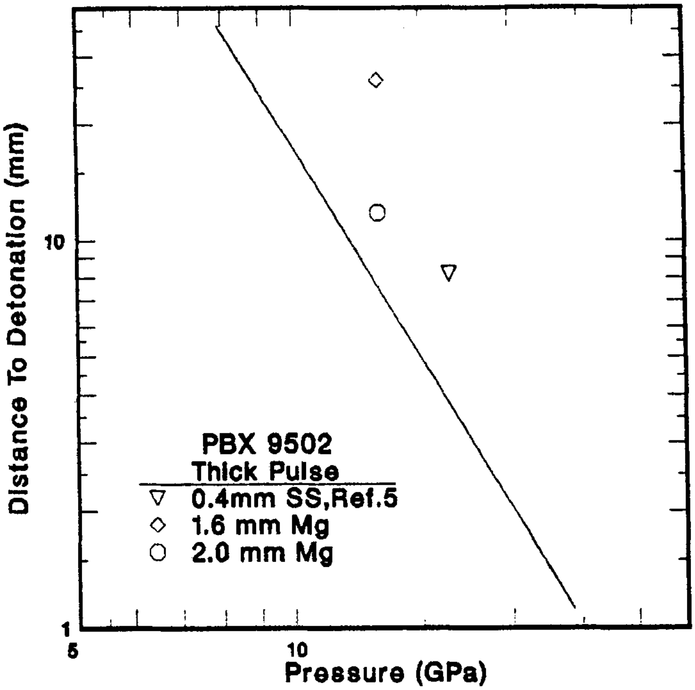

FIGURE 8

Run-to-detonation data for PBX 9502. Data for sustained shocks as well as short pulses generated by steel and magnesium flyer plates.