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MODELING OF EXPLOSIVE DESENSITIZATION BY PRESHOCKING

by

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ABSTRACT

Desensitization of heterogeneous explosives by shocks too weak to initiate propagating detonation occurs because the preshock desensitizes the heterogeneous explosive by closing the voids and making it more homogeneous. A higher pressure second shock has a lower temperature in the multiple shocked explosive than in single shocked explosive. The multiple shock temperature may be low enough to cause a detonation wave to fail to propagate through the preshocked explosive.

INTRODUCTION

Shock initiation of heterogeneous explosives proceeds by the process of shock interaction at density discontinuities, such as voids. which produces local hot spots that decompose and add their energy to the flow. The released energy strengthens the shock so that when it interacts with additional inhomogeneities, higher temperature hot spots are formed and more of the explosive is decomposed. The shock wave grows stronger and stronger, releasing more and more energy until propagating detonation occurs. The process has been numerically modeled using the technique called Forest Fire.[1] It describes the decomposition rates as a function of the Pop plot (the experimentally measured distance of run to detonation as a function of the shock pressure) and the reactive and nonreactive Hugoniots.

It has been observed that preshocking a heterogeneous explosive with a shock pressure too low to cause propagating detonation in the time of interest can cause a propagating detonation in unshocked explosive to fail to continue propagating when the detonation front arrives at the previously shock explosive. The resulting explosive desensitization was modeled using a Forest Fire decomposition rate that was determined only by the initial shock pressure of the first shock wave passing through the explosive.[2] This model could reproduce the experimentally observed explosive desensitization of TATB (triaminotrinitrobenzene) explosives previously shocked by short duration 25 and 50-kilobar pulses. It could not reproduce the observed results for low or high preshock pressure that do not cause a propagating detonation to fail.

The study to determine the mechanism of the explosive desensitization by preshocking using a three-dimensional reactive hydrodynamic model of the process was described in reference 3. With the mechanism determined, it was possible to modify the decomposition rate to include both the desensitization and failure to desensitize effects.

The three-dimensional modeling study demonstrated that the desensitization occurs by the preshock interacting with the holes and eliminating the density discontinuties. The subsequent higher pressure shock waves interact with a more homogeneous explosive. The multiple shock temperature is lower than the single shock temperature at the same pressure, which is the cause of the observed failure of a detonation wave to propagate in preshocked explosives for some ranges of preshock pressure.

The modification indicated by the three-dimensional study to the Forest Fire decomposition rate being limited by the initial shock pressure was to add the Arrhenius rate law to the Forest Fire rate.

The Forest Fire rate for TATB is shown in Fig. 1 along with the Arrhenius rate calculated using the temperatures from the HOM equation-of-state for the partially burned TATB associated with the pressure as determined by Forest Fire. We will examine several explosive desensitization experiments using a burn rate determined by Forest Fire limited to the initial shock pressure and the Arrhenius rate using local partially burned explosive temperatures.

EXPERIMENTAL STUDIES

Dick[4] performed a PHERMEX radiographic study of detonation waves in PBX-9502 (95/5 Triaminotrinitrobenzene/Kel-F binder at 1.894 g/cm^3) proceeding up a 6.5- by 15.0-cm block of explosive that was preshocked by a 0.635-cm steel plate moving at 0.08 (Shot 1698) or 0.046 cm/μs (Shot 1914). The static and dynamic radiograph for Shot 1698 are shown in Fig. 2. The preshocked PBX-9502 explosive quenches the detonation wave as it propagates into the block of explosive.

Travis and Campbell[5] performed a series of experiments studying desensitization of PBX-9404 (94/3/3 HMX/Nitrocellulose/CEF at 1.844 gm/cm^3) by shocks. The PBX-9404 explosive was 8 x 4 x 1/3 in. and cemented to a thick sheet of Plexiglas. It was immersed in water at various distances from a 6-in.-diam. sphere of PBX-9205 which served as the preshock generator. When the arrangement was fired, a detonation swept downward through the PBX-9404 and encountered an upward-spreading shock wave from the PBX-9205 generator. Events were photographed with a framing camera.

They concluded that the detonation in PBX-9404 is not quenched by a preshock of 7.5 kbars. An 11-kbar initial shock pressure required a time lapse of about 6 μs before the detonation wave failed and a 25-kbar preshock required less than 1 μs.

Dick[4] performed a PHERMEX radiographic study (Shot 1746) of a detonation wave in PBX-9502 turning a 90° aluminum corner and interacting with explosive preshocked by a shock wave that had previously traveled through the aluminum.

MODELING

The experimental geometries studied using PHERMEX shown in Fig. 2 were numerically modeled using a reactive hydrodynamic computer code, 2DL, that solves the Navier-Stokes equation by the finite-difference techniques described in Ref. 1. The users manual for the 2DL code is described in Ref. 7. For explosives that have been previously shocked, Craig[6] experimentally observed that the distance of run to detonation for several multiple shocked explosives was determined primarily by the distance after a second shock had overtaken the lower pressure shock wave (the preshock). To approximate this experimental observation, we programmed the calculation to use Forest Fire rates determined by the first shock wave or the rates determined by any subsequent release waves that result in lower pressures and lower decomposition rates. As suggested by the three-dimensional study, we added the Arrhenius rate using the local partially burned explosive temperatures to the Forest Fire rate. The HOM equation-of-state and Forest Fire constants used to describe PBX-9502 (X0290) and PBX-9404 are given in Ref. 1.

The calculated pressure and mass fraction contours for PHERMEX Shot 1698 are shown in Fig. 3 along with the radiographic interfaces.

The 2DL calculation had 50 by 33 cells to describe the PBX-9502 and 50 by 5 cells to describe the steel plate. The mesh size was 0.2 cm and the time step was 0.04 μs.

The PHERMEX shot was numerically modeled using various velocity steel plates. The results are shown in Table I. The results agree with the experimental evidence that detonation wave failure occurs in preshocked TATB shocked by steel plates with velocities of 0.046 and 0.08 cm/μs.

TABLE I. 9502 Desensitization Calculations

Steel Plate Velocity (cm/μs)	Preshock Pressure (kbar)	Result Upon Arrival of Detonation Wave
0.020	9	Detonates preshocked HE
0.030	14	Fails in preshocked HE
0.045	23	Fails in preshocked HE
0.080	50	Fails in preshocked HE
0.100	70	Fails in preshocked HE
0.120	90	Detonates preshocked HE and after 1.5 cm run
0.160	130	Detonates preshocked HE
0.200	180	Detonates preshocked HE

The Travis and Campbell experiments described previously can be evaluated using calculated multiple shock temperatures and solid HMX Arrhenius constants determined from Craig's single crystal shock initiation data described in Ref. 3.

The results are shown in Table II. Induction times less than 0.2 μs were calculated for the 7-kbar preshock that was observed to fail to quench a detonation wave. Induction times of 0.35 to 4 μs were calculated for the preshock pressures observed to have a time lapse before the detonation wave failed. Larger induction times were calculated for a 50-kbar preshock pressure; however, the 50-kbar preshock would build to detonation in 0.4 cm or 0.75 μs.

The experimental observations of Travis and Campbell are consistent with the desensitization being caused by the preshock making the explosive more homogeneous and reducing the explosive temperature upon arrival of the detonation wave by the multiple shock process.

TABLE II. 9404 Multiple Shock Results

First Shock (kbar)	Second Shock (kbar)	Temperature (°K)	Induction Time* (μs)
360	0	1669	0.051
7	360	1442	0.198
10	360	1368	0.345
15	360	1267	0.821
20	360	1185.1	1.87
25	360	1117.9	4.04
50	360	916.8	84.4

*Solid HMX, E = 34.5 kcal/g, Z = 4.0 x 10^4 μs^{-1}

The radiograph (1746) of a PBX-9502 detonation wave initiated by 12.7 mm Composition B-3 and a P-0.81 plane wave lens turning an embedded aluminum corner is shown in Fig. 4. The calculated density and mass fraction contours are shown in Fig. 5 along with the radiographic interfaces.

The jet initiation and penetration of bare explosive has been numerically modeled in Ref. 8. The initiation of explosives by jets that first penetrate barriers of inert materials in contact with the explosive has been shown to result in decreased sensitivity of the explosive to jet impact.[9] The bow shock wave that travels ahead of jet through the barrier can desensitize the explosive sufficiently that it cannot be initiated by the higher pressure generated near the jet interface.

To illustrate the effect of desensitization by preshocking resulting from jets interacting with barriers in contact with explosives,[9] we modeled the interaction of a steel jet with an initial velocity of 0.75 cm/μs and diameter of 0.15 cm with Composition B and with a steel barrier in contact with Composition B. The equation-of-state constants, Forest Fire, and Arrhenius rates used for Composition B are described in Ref. 1.

Figure 6 shows the initiation of detonation by the steel jet interacting with bare Compositon B. Figure 7 shows the calculated interaction of detonation by the jet interacting with 0.3 cm steel barrier and Composition B if desensitization does not occur. Figure 8 shows the calculated failure to initiate the Composition B when desensitization by the bow shock ahead of the jet is permitted to occur.

These calculations model the effect of barriers that result in decreased sensitivity of explosives to jet impact.

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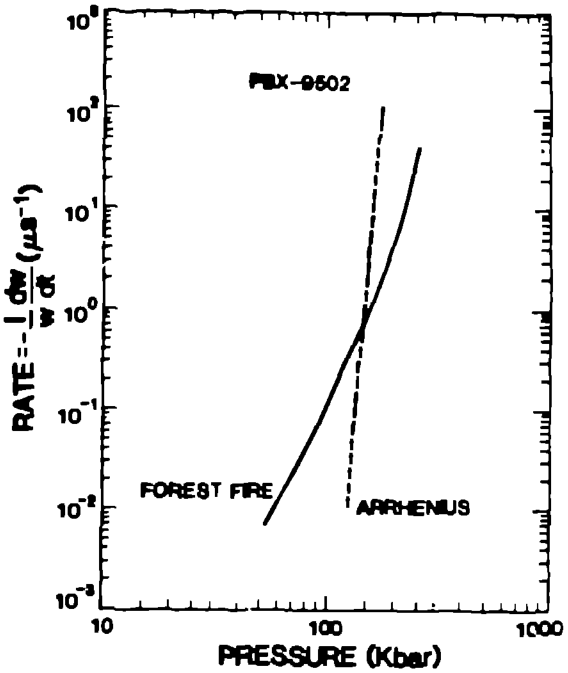

FIGURE 1
The burn rate as a function of pressure for the Forest Fire burn model and the Arrhenius rate law using the HOM temperatures associated with the Forest Fire pressures.

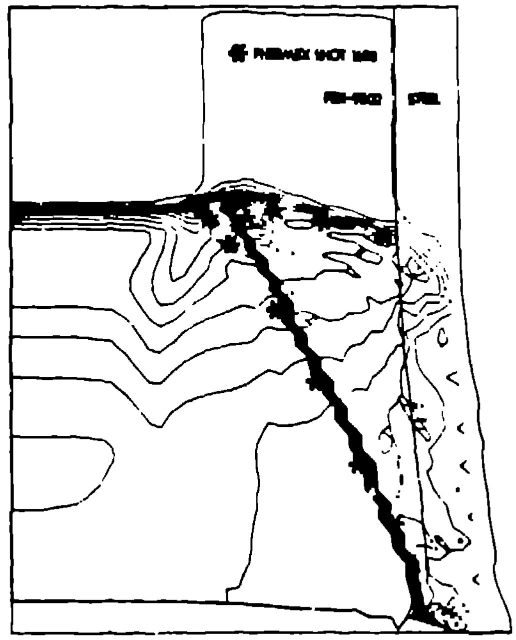

FIGURE 3
The pressure and mass fraction contours for a detonation wave in PBX-9502 interacting with explosive that had been previously shocked to 50 kbars. The PHERMEX radiographic interfaces are shown. The mass fraction contour interval is 0.1 and shown as a thick almost solid line. The pressure contour interval is 40 kbars.

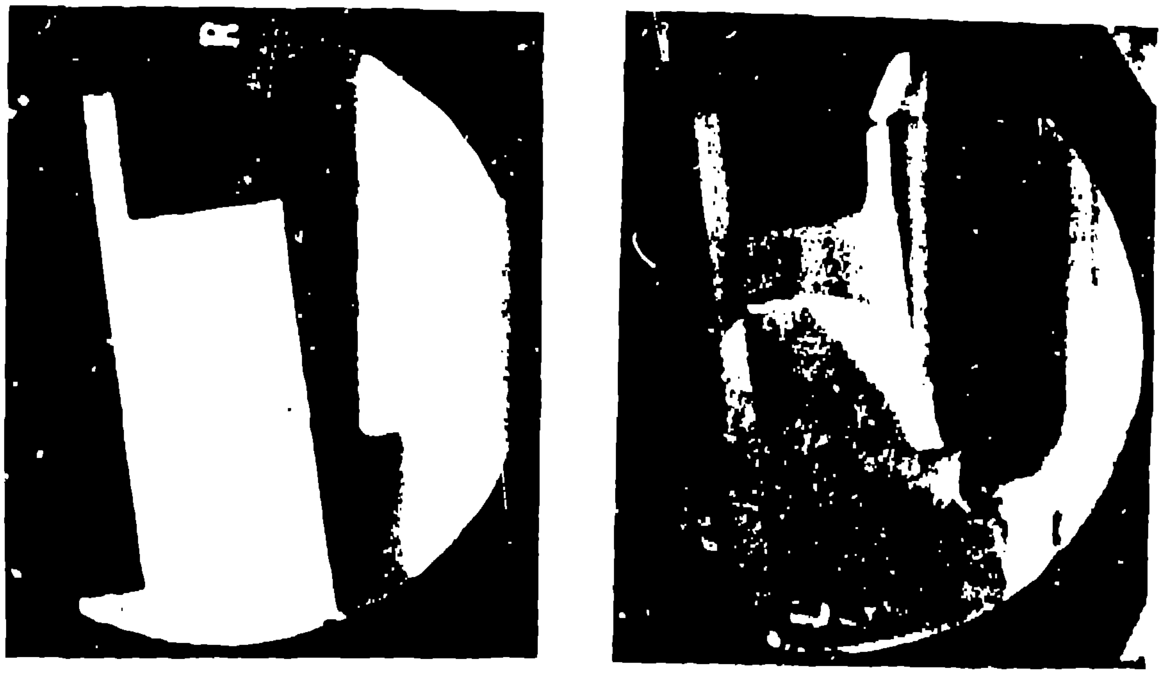

FIGURE 2
Static and dynamic radiograph 1698 of PBX-9502 shocked by a 0.635-cm-thick steel plate going 0.08 cm/μs and initiated by 2.54 cm of TNT and a P-40 lens.

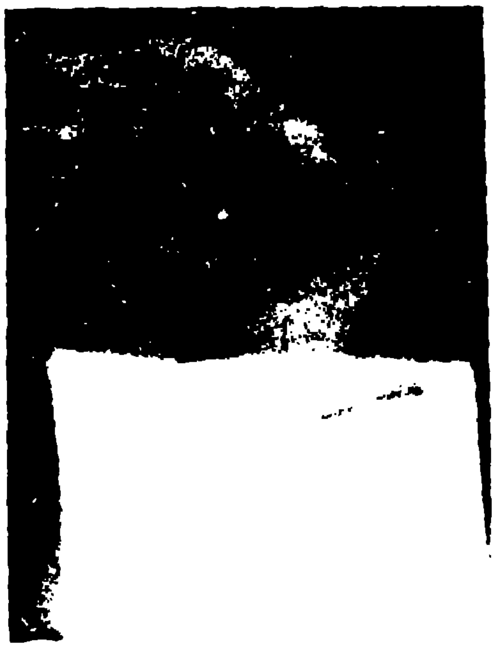

FIGURE 4
e dynamic radiograph 1746 of a PBX-9502 detona-
on wave turning an aluminum corner and inter-
ting with preshocked explosive.

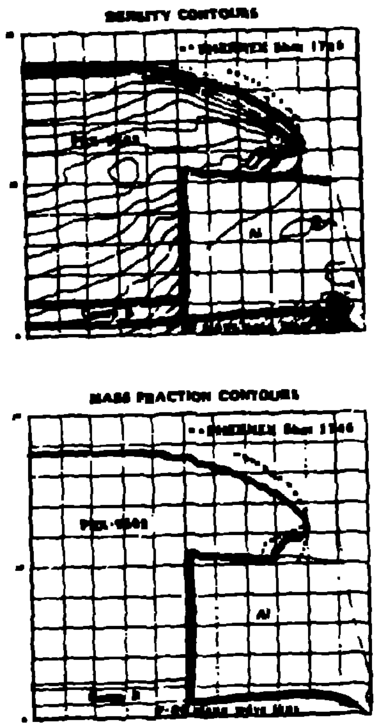

FIGURE 5
The calculated density contours with a contour interval of 0.2 cc/gm and mass fraction contours along with the PHERMEX radiographic interfaces are shown for a PBX-9502 detonation wave turning an aluminum corner and interacting with preshocked explosive.

FIGURE 6
The density and mass fraction contours at 1.0 μs for a 0.15 cm diameter steel rod initially moving at 0.75 cm/μs penetrating Composition B. The density contour interval is 0.2 cc/gm. The mass fraction contour interval is 0.1.

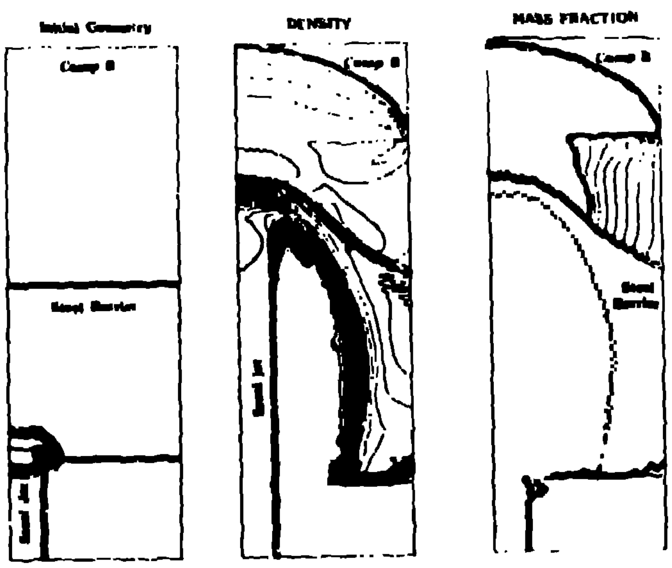

FIGURE 7
The density and mass fraction contours at 1.5 μs for a 0.15 cm diameter steel rod initially moving at 0.75 cm/μs penetrating a 0.3 cm thick steel plate in contact with Composition B. The calculation assumes desensitization does not occur. The initial geometry is shown.

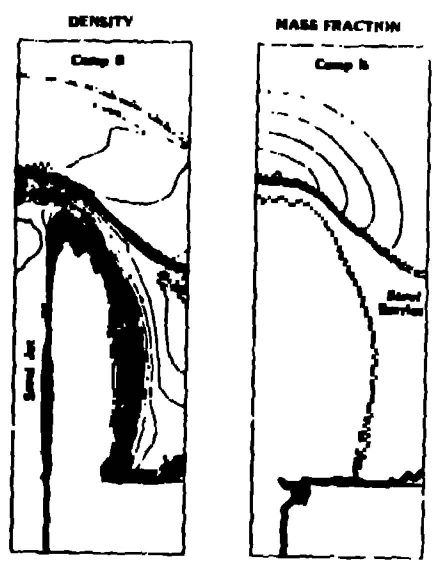

FIGURE 8
The density and mass fraction contours at 1.5 μs for the system shown in Fig. 7. The desensitization of the explosive by the weak bow shock is included in the calculation.