AIR CUSHION EFFECT IN THE SHORT-PULSE INITIATION OF EXPLOSIVES *

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When thin flyer plates are used to shock initiate high explosive (HE), any air present ahead of the flyer may cause a significant desensitization of the HE. The effect of the air in cushioning the impact of plastic flyers faced with metal films is analyzed here with MACRAME, a code which calculates wave interactions and traces wave propagation. We find that the second air shock into the HE has sufficient pressure to collapse the HE to crystal density or higher. Precompressed regions of HE do not react rapidly when the main impact pulse does arrive. Define y^* as the depth where the major shock overtakes the precompression wave (for no air $y^* \rightarrow 0$). For various flyers and air combinations, we compare pressure profiles at $y = y^* + \epsilon$. The shock pressure profile associated with metal film impact may be greatly attenuated at the depth y^* . Density profiles ($\rho(t)$ at y) show that the shock heating for $y > y^*$ is greater than that for $y < y^*$.

INTRODUCTION

The interplay between shock pressure, P , and shock duration, t , is of interest in defining threshold loading conditions for initiation of detonation of high explosives (HE). An "electric gun" (1) has been used at LLNL for such studies of one-dimensional planar initiation of HE; it uses thin, large-diameter dielectric flyer plates driven electrically. The analysis presented here addresses the use of metal-coated plastic dielectric films for similar studies, and directs attention at the effect of air in the flight path of a flyer plate.

There are two main effects due to air trapped between the flyer plate and the HE. First, the mass and back pressure of the shocked air tends to decelerate the flyer. Secondly, impingement of air shocks onto the HE surface may cause precompression of the HE. If the precompressed region of the HE is significantly compacted, this region can be substantially desensitized and it may not react upon arrival of the main shock due to flyer-plate impact. Setchell(2) showed that granular HNS, precompressed by a ramp-shaped acceleration wave, did not react upon subsequent arrival

of a strong shock, until the ramp wave had steepened into a shock.

The problem we have addressed may be stated as follows. A plastic backing plate is coated with a thinner coating of metal. This coated plate impacts a slab of HE. Air trapped between the flyer and HE mitigates this impact. Our interest is in evaluating the shape of the loading pulse that influences the initiation of the HE. The 1-D geometry of a reference problem is sketched in Fig. 1. We compare variations against the results of this problem. The plastic base layer is $80 \mu\text{m}$ thick, the plate is assigned an initial velocity of 4 km/s and the explosive is TATB at a density of 1.81 g/cm^3 in all the examples we address, while all other parameters are varied. Only the mechanical response of the HE is considered in our calculations; we have not introduced a reaction rate law or any energy release.

THE MACRAME CODE AND PHENOMENOLOGY

In analyzing this problem we needed to resolve a rather wide range of interactions, on both distance and pressure scales. This included the states of singly shocked air, multiply shocked air, air-HE

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FIGURE 1. Reference One-Dimensional Problem

and plate-HE interactions.

The code chosen for this analysis was the MACRAME code, which calculates 1-D wave interactions and traces wave propagation. The definition obtained in these calculations is sharp, with no rounding due to artificial viscosity. For MACRAME, coarse resolution in one area and fine resolution in another are compatible. For the EOS of TATB(3) we used a quadratic $u_s(u_p)$, $u_s = 2.75 + 2.35u_p - 0.13u_p^2$ (km/s), appropriate to a compacted density of 1.937 g/cm^3 . A snowplow model with a Grüneisen gamma of 2.0 was used to represent the porous explosive. An ideal gas EOS was used to represent the air. This leads to stiffer shocks in the reverberating region; the actual shocks will be softer and more numerous due to extra internal energy channels opening in the air molecules. However, this slightly changed structure will only introduce slight modifications to the overall patterns that we calculate.

Figure 2 illustrates interactions close to the HE surface, showing the propagation paths of the first and second air shock interactions within the HE. The time origin, $t = 0$, was chosen to be that time the flyer would impact the HE if there were no air in the intervening gap. The figure is a section of the overall $x-t$ diagram for the problem. The first air shock interaction drives a pressure of

FIGURE 2. Wave Propagation Near the Surface of Granular TATB Acceptor Charge. Shocks and interfaces are shown as solid lines; rarefaction wavelets are dashed. All lines used for calculations are shown: this sometimes makes the strong and important waves difficult to distinguish.

0.14 GPa into the HE, which is similar to the static pressure used to construct the sample. Thus it is believed that this transient pressure will not effect any further compaction, and this wave trajectory is designated the "discarded wave" in Fig. 2. Interaction of the second air shock (a reverberation between the HE and the oncoming plate) with the HE drives about 1.8 GPa into the HE, and this is certainly enough to compact and precompress the HE. The Lagrangian distance where this pre-compression wave is overtaken by the main shock produced by the flyer plate is designated y^* . It is interesting to note that the value of y^* varied only slightly, 29–35 μm , over the entire set of examples that are described below.

Ordinarily, for a snowplow model, the code would collapse a material from its porous state to

a compacted state for any first wave. This would lead to incorrect behavior for the initial weak air shock. We installed an option to ignore initial weak waves less than some threshold. This permits us to ignore the first air shock in this problem and let the next one compact the porous explosive.

The time for pore closure in the HE was estimated to be 0.4 ns, based upon a free-surface velocity relaxing from a 1.8 GPa shock and a HE particle radius of $0.7 \mu\text{m}$, calculated from the surface area of $2.3 \text{ m}^2/\text{g}$. At a shock velocity of 3.5 km/s, this time for pore closure corresponds to shock front travel of $1.4 \mu\text{m}$, which is much less than our typical value for y^* . Thus we may conclude that nearly all the material between the impact surface of the HE ($y = 0$) and y^* has been pre-compressed and "deadpressed" before arrival of the main shock. The portion of the shock waveform that is useful for initiation of the HE then is the waveform which exists at y^* and deeper into the HE. Density profiles ($\rho(t)$ at y) show that the shock heating for $y > y^*$ is greater than that for $y < y^*$, and this is consistent with the interpretation of deadpressing at $y < y^*$.

Our reference conditions were defined to include 1 atm air and a $5 \mu\text{m}$ coating of nickel on the plastic backing sheet. The shock pressure profiles are shown in Fig. 3 at depth intervals of

FIGURE 3. Pressure Profiles at Various Depths into HE in Reference Problem.

$10 \mu\text{m}$ into the HE. These show "preshock" rever-

berations that vanish by the time the shock has traveled $30 \mu\text{m}$ into the HE. This is a depth sufficiently great that the high-pressure step from impact of the nickel coating has been largely attenuated away.

PARAMETER STUDIES

Parameter studies were done through variations on the reference problem.

We first varied the air pressure ahead of the flyer, at levels of 0, 1 and 2 atm. Figure 4 shows

FIGURE 4. Shock History at Depth y^* as a Function of Air Pressure in Flight Path

the shock history at y^* , denoted $P_{y^*}(t)$, for all three cases. Of course, $y^* = 0$ for a vacuum, so there has been no attenuation of the leading pressure step in the waveform. There also is no back pressure to retard the flyer plate in a vacuum, so the magnitude of the leading pressure step is higher. The difference in magnitude of the leading shock step and the impulse delivered to the HE is quite large as the pressure is increased 0-1-2 atm. The 2 atm case may be viewed as an indication of the detrimental effects that any excess pressure ahead of the flyer would have, e.g., due to blowby of the gases that are accelerating the plate.

We next varied the metal material coated onto the plastic backing, holding the metal coating thickness constant at $5 \mu\text{m}$. The coatings were of gold (Au), nickel (Ni), aluminum (Al), and no

FIGURE 5. Shock History $P_{y^*}(t)$ for Metal-Coated Plastic Flyers: (a) Coating 5 μm thick, (b) Nickel coating 5 μm thick, and all other coating thicknesses adjusted to match nickel areal density.

coating (just Kapton). Because the densities of the coating varied, the initial momentum of the flyer at impact varied, and this is reflected in the $P_{y^*}(t)$ shock waveforms shown in Fig. 5(a). The gold coating delivered the highest shock pressure and the highest impulse into the HE, and these quantities declined with decreasing density and impedance of the coating material.

Perhaps a more equitable comparison of the effects of coating material choice is to hold the momentum constant. This was done by adding coating of a fixed areal density for each material onto the 80 μm thick Kapton backing plate; the all-Kapton flyer was made thicker to hold the flyer mass constant. The reference problem, with 5 μm of nickel, was one of this set, and all other coatings were adjusted in thickness to match this mass of nickel. The waveforms shown in Fig. 5(b) show that, with constant impulse in the pulses delivered by the various flyers, there is a tradeoff between peak pressure and shock duration. The highest shock pressure is still delivered by the gold coating, but only by a slight margin over the nickel. The shocks from both coatings are clearly being attenuated.

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CONCLUSIONS

The main conclusions from this work are:

- (1) For thin flyers, air present in the flight path can significantly reduce the impact velocity and momentum of the flyer. This effect is magnified if the pressure is increased, as due to blowby of the driving gas.
- (2) Compaction of the acceptor HE occurs due to the compressive loading from interaction of the air shock driven by the flyer, and consequent pre-compression and deadpressing will occur to some depth in granular acceptor HE.
- (3) The depth y^* of this deadpressing scales with the initial flyer to HE distance. For the variations we studied it is deep enough to allow attenuation of the loading pulse from thin metal coatings on the face of a plastic flyer plate.

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