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INITIATION OF DETONATION IN MULTIPLE SHOCK-COMPRESSED LIQUID EXPLOSIVES

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Abstract. Initiation and resulting propagation of detonation via multiple shock reverberations between two high impedance plates has been investigated in amine-sensitized nitromethane. Experiments were designed so that the first reflected shock strength was below the critical value for initiation found previously. Luminosity combined with a distinct pressure hump indicated onset of reaction and successful initiation after double or triple shock reflection off the bottom plate. Final temperature estimates for double or triple shock reflection immediately before initiation lie between 700-720 K, consistent with those found previously for both incident and singly reflected shock initiation.

Keywords: Detonation, initiation, pre-compression, temperature, nitromethane.
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INTRODUCTION

The initiation of homogeneous liquid explosives by planar shock waves has been studied extensively. There exists, however, disagreements over the mechanism of the initiation process. The classic view suggests that initiation is governed by thermal decomposition after shock compression leading to the formation of a "super-detonation" propagating in the explosive originally compressed by the incident shock and eventually overtaking the latter [1-3]. In contrast to thermal decomposition behind the shock, Dremin [4] and Walker et al. [5] suggested that detonation ignition is controlled by the excitation of kinetic motion degrees of freedom within the shock front as it propagates into the explosive.

In order to further investigate the mechanism of initiation in homogeneous explosives, others have performed experiments whereby a reflected shock was used as a means to bring the explosive to a thermodynamic state off of the principle Hugoniot prior to initiation. Presles et al. [6] attempted to initiate pure nitromethane in this fashion using aluminum as the reflective surface. As no detonation was observed, it was concluded that the reflected shock was insufficiently strong. Higgins et al. [7,8] conducted incident and reflected initiation experiments in amine-sensitized nitromethane using steel as a reflective surface or anvil. They found the critical reflected shock pressure to reach at least 1.4 times that of the critical incident shock value. The temperatures for incident and reflected initiation, however, are equal thus suggesting that temperature seems to be the controlling variable in initiating detonation, independent of the shock path used.

To further examine the limit of thermal decomposition as the mechanism for detonation initiation at higher degrees of pre-compression, the present study examines the results from attempts at initiating detonation in a homogenous liquid explosive through multiple shock reflections between two high impedance anvils.

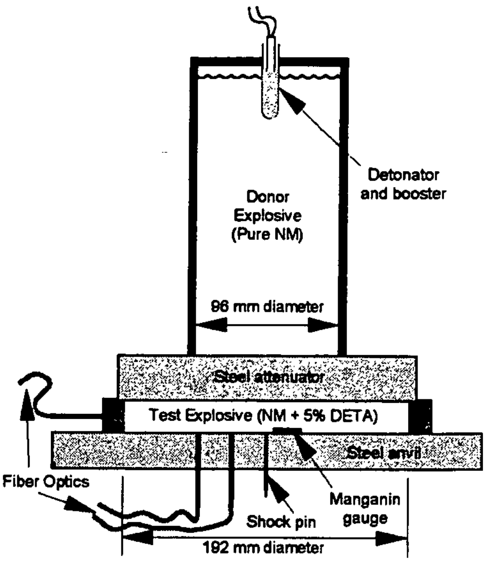

Figure 1. Schematic of experimental setup

EXPERIMENTAL DETAILS

The experiments are conducted using a configuration similar to that used previously [7,8], as shown in Fig. 1. A donor charge consisting of pure nitromethane (NM) is detonated and sends a shock wave through a steel attenuator. The shock then transmits into the receptor containing the test explosive, before reflecting on a steel anvil instrumented with light pipes and a manganin gauge (Dynasen model MN4-50-EK) as shown in Fig. 2. A thin Mylar sheet (0.25 mm thick) of size only slightly larger then the gauge had to be inserted between it and the metal anvil for electrical insulation. Gauge error was estimated at ±5% over the range of pressures used in these tests.

The gauge is located 5 mm from the center, whereas anvil mounted light pipes are positioned at radii of 25 and 50 mm. The latter consist of polished acrylic rods 32 mm long by 6.35 mm in diameter. As the reverberating shock does not reach the receptor inner diameter during the time of interest, side-on light pipes like those used previously [7,8] (essentially a bare fiber looking through a 80 μm thick Mylar window) observe the event through the wall surrounding the test charge. Two arrays of light pipes spaced 90 degrees apart are used in order to confirm initiation in the charge center. Luminosity from each light pipe is transmitted through a 1 mm acrylic fiber into an amplified photodiode circuit (Thorlabs model PDA55).

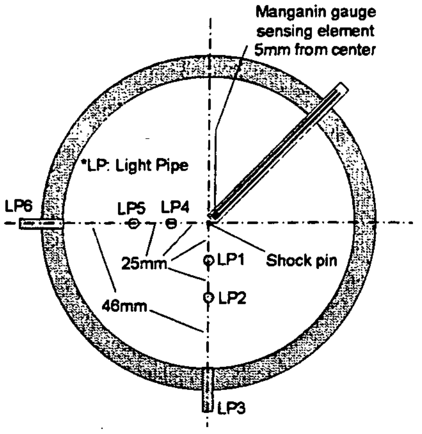

Figure 2. Receptor instrumentation layout

Thicknesses of 22.3-25.5 mm for the attenuator, 6.2 mm for the receptor and 12.7-25.4 mm for the anvil are chosen such that multiple reverberation of a single shock within the receptor is possible on the time scale of the experiment. The test explosive consists of commercial grade NM blended with 5% diethylenetriamine (DETA) sensitizer; the same prototypical mixture used previously [7,8] for incident and reflected initiation studies. The uncompressed liquid explosive has a measured detonation velocity of 6.0 km/s. Initial liquid temperature is maintained between 23-30°C, and since the room temperature critical diameter for NM+5%DETA is less than 1 mm, the current receptor thickness should be sufficient to propagate a steady detonation.

RESULTS AND DISCUSSION

Results from an experiment using a 22.3 mm attenuator with a 12.7 mm anvil are presented in Fig. 3. Zero time corresponds to the arrival of the first incident shock on the anvil. The double shock pressure rise to 4.9 GPa on first reflection is a result of using Mylar insulation between the gauge and the anvil. The pressure history at the anvil surface shows two plateaus, indicating two reflections, before rising to a peak value of 11.37 GPa at 4 μsec. This time also coincides with the appearance of luminosity as observed though the wall mounted (side-on) light pipes. It is

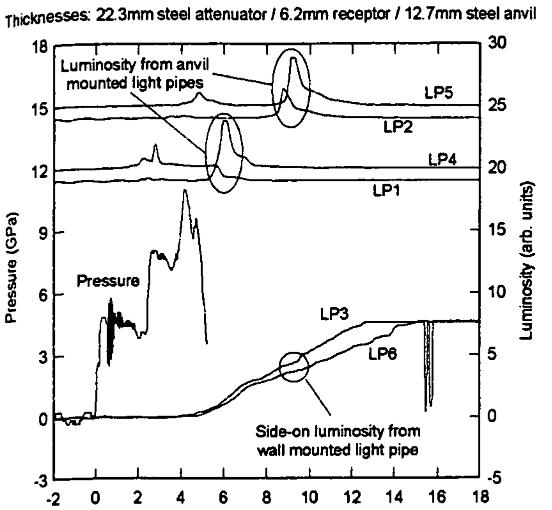

Figure 3. Pressure and luminosity records for the 22.3 mm thick steel attenuator

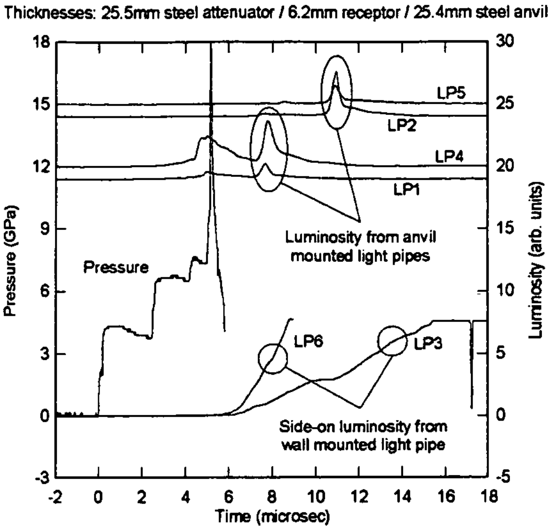

Figure 4. Pressure and luminosity records for the 25.5 mm thick steel attenuator

important to keep in mind that manganin gauges deployed in these experiments have a design pressure slightly in excess of 10 GPa. Thus, they cannot be expected to record pressure quantitatively after initiation. The earlier luminosity observed from the anvil mounted (end-on) light pipes, between 1-3 μsec and 3-5 μsec at 25 and 50 mm from the center respectively, is associated with shocked air at the anvil-air interface underneath the charge. Simplified shock trajectory estimates as well as LS-DYNA simulations further support evidence of shocked air luminosity at those times.

Stronger and sharper light signals from these end-on light pipes are observed after the final pressure jump, where peak-to-peak time of arrival between light pipes gives an average velocity of 8.0 km/sec in both radial directions. The side-on light pipe shows a momentary drop in luminosity at 15.5 μsec as a result of the detonation reaching the wall. Increase in luminosity shortly thereafter results from the shock traversing the Mylar window and emerging into air. Average velocity based on arrival time between the 50 mm end-on radial light pipe and the wall is 7.1 km/sec in both radial directions. Detonation decay in the radial direction results from lower sample pre-compression closer to the receptor wall. Both pressure jump and average velocities confirm that detonation successfully initiated within the receptor.

Fig. 4 shows results of an attempt at achieving more reverberations during pre-compression using both a thicker attenuator and anvil of 25.5 and 25.4 mm respectively. The thicker anvil resulted in a delayed shock arrival at the anvil-air interface as evidenced by the first luminosity peak at 5 μsec. This time also coincides to when the incident shock emerges underneath the anvil at the light pipe locations. Both pressure gauge and wall mounted light probes indicate initiation of detonation after three shock reflections. Finally, average detonation velocities between light probes at 25-50 mm and 50-96 mm (wall) are 7.8 km/sec and 6.8 km/sec respectively for both radial directions.

Successful initiation requires the application of a shock of sufficient strength and duration, which in turn will be affected by charge boundary conditions. The foregoing apparatus, however, is geometrically similar to that used in a previous work [8], so a comparison can be made in order to examine the influence of compression path and pressure on the initiation process. The Winey et al.[9] equation of state, which calculates temperature in pure nitromethane under multiple shock reverberations, is used assuming that the small concentration of DETA present in the test mixture has negligible effects in the unreacted NM temperature changes. Since the experiments

Table 1. Shock pressures and temperatures during pre-compression

Initiation technique	Pressure (GPa)	Estimated temperature (K)
Incident shock initiation	4.3[8]	720
Single reflected shock initiation*		
Incident	2.5-2.8[8]	576-602
Reflected	6.0-6.5[8]	701-724
Double reflected shock initiation*		
1st incident	2.02**	532
1st reflected	4.80	652
2nd incident	6.29**	685
2nd reflected	7.89	715
Triple reflected shock initiation*		
1st incident	1.84**	515
1st reflected	4.35	632
2nd incident	5.65**	664
2nd reflected	6.64	683
3rd incident		
3rd reflected	7.49	

*From a steel anvil **Calculated

detailed here only had one pressure gauge mounted on the steel surface, the NM shock pressure immediately before reflection off the anvil is calculated using LS-DYNA. Conditions similar to those found in experiments of Figs. 3 and 4 are simulated and results are presented in Table 1. For the case with a double reflection, a final temperature of 715 K is obtained. For the triple reflection pre-compression test, however, calculated pressures beyond the second reflection were not successful at reproducing the measured values. Although final temperature cannot be estimated, experimental final shock pressure is found to be slightly lower then that for the double reflection case, which should result in a lower final temperature.

CONCLUSIONS

An estimated temperature of 700-720 K seems to be reasonable for the double or triple shock reflection leading to a successful initiation of detonation. This temperature value is consistent with that obtained previously from the incident and singly reflected shock initiation tests. This suggests that temperature is a dominant variable for initiation at the studied shock pre-compression levels, regardless of the difference in shock path and pressure magnitude.

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