Investigation of Lateral Effects on Shock Initiation of a Cylindrical Charge of Homogeneous Nitromethane

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Introduction

When a shock wave is transmitted into a condensed explosive, initiation of detonation will occur if the following two conditions are satisfied: the shock strength must be above a certain minimum value and the shock wave must last a minimum amount of time. The minimum duration of the shock necessary for initiation depends on the shock strength; a stronger shock will not need to be sustained as long as a weaker one in order to initiate a detonation.

In order to quantify these two parameters, many experiments have been conducted to date [1-3]. These experiments are typically conducted so as to obtain one-dimensional behavior within the explosive tested. To achieve one-dimensional behavior, cylindrical charges with large diameters are used such that the inner core of the test explosive remains unaffected by lateral rarefaction waves coming in from the outer edges of the charge. From the point of view of the core, the charge is effectively infinite in diameter since no information from the edges reaches the charge axis. Finally, to ensure a true one-dimensional process, the shock is transmitted to the test sample via a flyer plate or a planar wave generator (PWG).

On the other hand, most practical applications involving explosives require smaller, finite diameter charges and point initiation (as opposed to initiation by a one-dimensional planar shock wave). It is already known that the data accumulated for one-dimensional initiation cannot be applied directly to multidimensional initiation situations. Usually, empirical relations that are apparatus dependent are derived; but no theory can predict a priori whether initiation will occur in a given configuration. Before any such theory can be developed, it is necessary to understand how each type of two-dimensional effect influences initiation.

Among these effects, there is the interaction of the incident shock with the charge capsule wall, which can affect the effective pressure to which the explosive is brought [4, 5]. Moreover, shock curvature causes non-uniform shock strength and duration across the diameter of the charge [6-8]. Finally, lateral expansions accentuate curvature by slowing down the shock near the edges of the charge, which has the effect of causing the shock pressure and duration to be decreased near the edges.

In this study, these effects were investigated by using a gap test [9] configuration in which the test capsule material and the charge diameter were varied. Changing the capsule material permits varying the shock impedance of the confining wall. Higher impedance confinement prevents mass

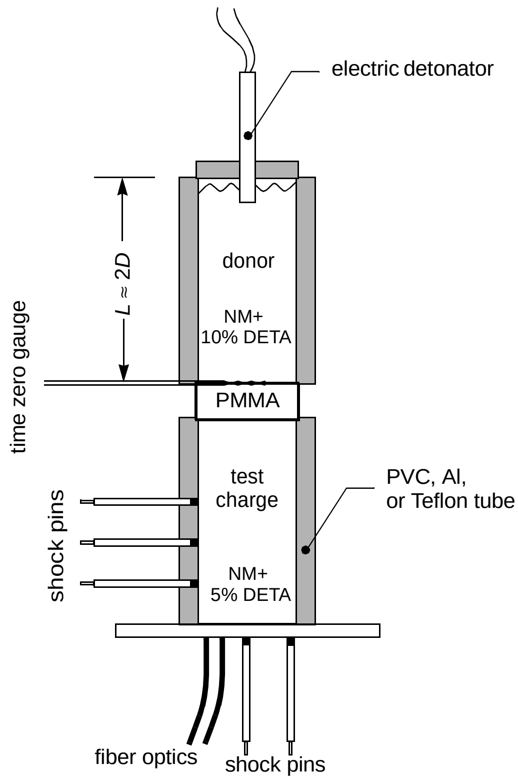

Fig. 1 Schematic of charge.

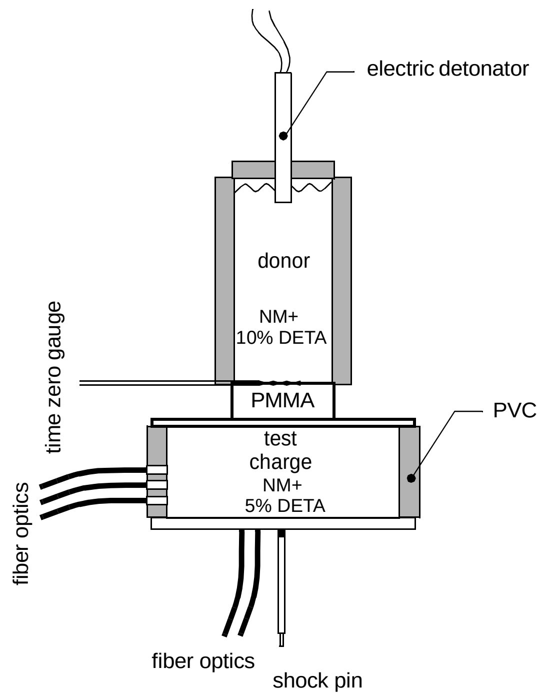

Fig. 2 Schematic of charge with liquid confinement.

divergence behind the shock, which keeps the pressure high in the explosive. The effect of varying the charge diameter is to change the time required for lateral rarefactions to reach the inner core of the explosive.

Experiments

The charge setup is as shown in Fig. 1. Three capsule materials were tested for charges of 25 mm diameter: gray polyvinyl chloride (PVC), Teflon, and aluminum. The capsule wall thickness was kept the same for all three materials, at 0.5 cm. Experiments in which the donor was 25 mm in diameter while the receptor was 50 mm in diameter (and 25 mm in height) were also performed (see Fig. 2). This is equivalent to having a 25 mm diameter test charge surrounded by a ring of test explosive, thus the confinement is effectively provided by liquid NM + 5% DETA. In this manner, the confinement matches the impedance of the test explosive. Finally, three charge diameters were tested for charges contained in PVC capsules (configuration as in Fig. 1): 25 mm, 50 mm, and 100 mm.

The donor charge generates the shock wave that will be transmitted into the test charge. The donor charge was filled with nitromethane (NM) sensitized with 10% by weight of diethylenetriamine (DETA) and initiated by an electric detonator. The donor assembly height was always twice its diameter.

The detonation from the donor assembly impacts a layer of inert material (Polymethylmethacrylate or PMMA) and the transmitted shock attenuates as it propagates through it [10]. The thicker the inert barrier, the weaker the shock transmitted to the test explosive. A series of tests were conducted to measure the rate of shock decay in PMMA via measurements of shock arrival time and pressure at various PMMA thicknesses for each of the three charge diameters.

Finally, the shock enters the test charge and detonation initiation is determined with diagnostics located along and under the charge. The test explosive used in this study is NM + 5% DETA. Piezoelectric shock pins that emit a current when shocked are located along the charge to measure shock or detonation velocity. Shock pins are also located under the charge along a radius of the charge to measure shock planarity in the test charge (in some shots, one shock pin was also placed under the capsule wall to measure the shock speed in the wall compared to that in the test explosive). Furthermore, fiber optics are located along the radius of the charge to detect light so as to determine where the detonation was first initiated. In some shots, fiber optics were also located along the charge. The light transmitted by the fiber optics was monitored via photodiodes.

Results and Discussion

In Fig. 3, the diameter of the charge is plotted with the corresponding critical pressure for initiation (the charge configuration is as in Fig. 1). The effect of increasing the charge diameter is to lower the shock pressure necessary to initiate detonation. This is a result of the fact that the core of smaller diameter charges is affected by lateral expansions earlier than in larger diameter charges. Thus, the shock duration being less in smaller diameter charges, the shock strength must be greater to initiate the charge. This is consistent with the results of de Longueville et al. [2] who found that the minimum shock duration is about the same as the induction time of the explosive. Since the axes are logarithmic, we see that for large diameters, the critical pressure for initiation changes very little as we vary the diameter. In this range where charge diameter does not affect critical pressure, the lateral expansion effects can be neglected.

The effect of changing the impedance of the confinement does not yield the expected results (Fig. 4). In Fig. 4, the critical gap thickness for 25 mm diameter charges is plotted for three different capsule materials (PVC, Teflon, and aluminum) in order of increasing shock impedance

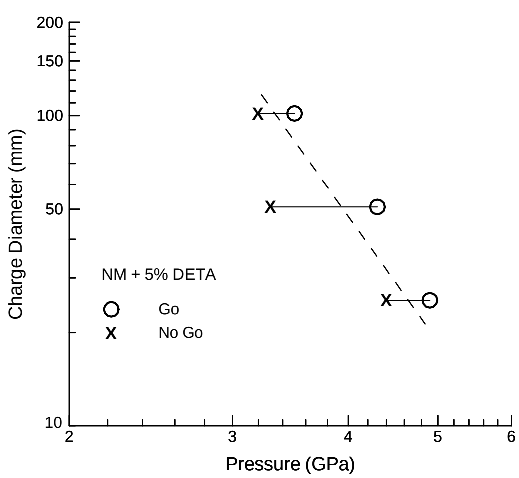

Fig. 3 Effect of scale on critical pressure

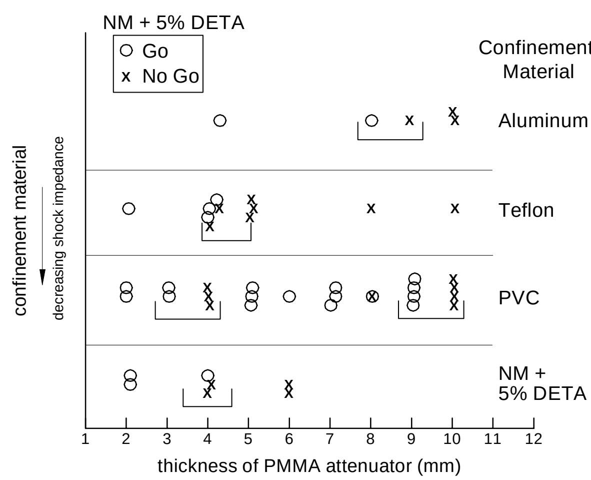

Fig. 4 Effect of confinement material on gap thickness.

(aluminum having the highest impedance). Results from experiments with the charge configuration of Fig. 2 are also shown in Fig. 4, labeled as “NM + 5% DETA” confinement since the larger diameter liquid explosive acts as the confinement for the core of the test explosive. Note that the y-axis is not to scale; it only indicates which materials have the highest and lowest impedances.

It can be seen in Fig. 4 that experiments with PVC confinement give an unusual result; two different critical thicknesses of inert gap are observed. This means that a 3 mm gap will result in initiation, a 4 mm gap will not initiate detonation, but increasing the gap thickness to 5 mm does result in initiation again. The gap must be increased to 10 mm in order for no further initiation to be observed. The first critical thickness, corresponding to a shock pressure of ~ 8 GPa, is believed to be the result of direct initiation by the incident shock, since this value agrees with the critical thickness obtained in test charges with a larger diameter that do not have wall interactions. The other mode of initiation, corresponding to a much weaker transmitted shock of 5 GPa, is likely the result of interaction with the test capsule walls. A similar result is obtained with an aluminum capsule, even though aluminum has a much higher impedance. Teflon apparently only exhibits the first “direct” mode of initiation, with a critical gap thickness around 4-5 mm, despite the fact that Teflon has an intermediate value of impedance compared to PVC and aluminum. Teflon, unlike PVC and aluminum however, has a lower acoustic speed than nitromethane. This suggests that it is the presence of a precursor shock in the confinement, rather than the impedance of the capsule material, that determines if initiation due to wall interaction occurs.

Conclusion

A method based on the gap test was developed to investigate the multidimensional effects that can influence shock initiation of homogeneous sensitized nitromethane. The parameters tested were charge diameter and charge capsule material impedance. Both of these parameters can affect shock strength or shock duration.

It was found that small diameter charges need a greater shock pressure to initiate detonation. This was attributed to the fact that lateral expansion waves reach the central core of the explosive earlier in small diameter charges than in large diameter charges, which has the effect of reducing shock duration and pressure to a greater extent in small diameter charges.

It was also found that for charge diameters much larger than the explosive’s critical diameter, the impedance of the confining material does not play as significant a role as it does in critical diameter measurements. Indeed, no regular trend seems to exist between high and low confinement impedances. On the other hand, it should be noted that the presence of precursor shocks in the confinement material seems to affect the value of the critical initiation pressure significantly. Therefore, in this initiation regime, hot spots could come into the picture (due to cavitation, etc.) and, as such, effective shock pressure and duration may no longer be easily determined because of the many complex interactions involved. This result has implications for the interpretation of gap tests, since different mechanisms may be responsible for initiation depending on subtle details of the test (dimensions, materials, etc.).

References

1. F. E. Walker, R. J. Wasley, “Initiation Patterns Produced in Explosives by Low-Pressure, Long Duration Shock Waves,” *Combustion and Flame*, vol. 22, pp. 53-58, 1974.
2. Y. de Longueville, C. Fauquignon, H. Moulard, “Initiation of Several Condensed Explosives by a Given Duration Shock Wave,” *6th Symposium on Detonation*, pp. 105-114, 1976.
3. S. A. Sheffield, R. Engelke, R. Alcon, “In-Situ Study of the Chemically Driven Flow Fields in Initiating Homogeneous and Heterogeneous Nitromethane Explosives,” *9th Symposium on Detonation*, pp. 39-49, 1989.
4. L. B. Seely, J. G. Berke, M. W. Evans, “Initiation of Detonation during Gap Testing of Liquids,” *AIAA Journal*, Vol. 5, No. 12, pp. 2179-2181, 1967.
5. D. R. Hardesty, “An Investigation of the Shock Initiation of Liquid Nitromethane,” *Combustion and Flame*, vol. 27, pp. 229-251, 1976.
6. F. E. Walker, R. J. Wasley, “Initiation of Nitromethane with Relatively Long-Duration, Low-Amplitude Shock Waves,” *Combustion and Flame*, vol. 15, pp. 233-246, 1970.
7. H. R. James, M. D. Cook, P. J. Haskins, “The Response of Homogeneous Explosives to Projectile Attack,” *11th Symposium on Detonation*, pp. 581-588, 1998.
8. M. D. Cook, P. J. Haskins, R. I. Briggs, P. Cheese, C. Stennett, J. Fellows, “High Speed Observation of Fragment Impact Initiation of Nitromethane Charges,” *Shock Compression of Condensed Matter* - 1999, American Institute of Physics, pp. 793-796, 1999.
9. M. Suçeska, *Test Methods for Explosives*, Springer-Verlag, New York, p. 45, 1995.
10. Ch. Klee, M. Kroh, D. Ludwig, “Experiments on the Attenuation of Shock Waves in Condensed Matter,” Proceedings of the 1981 Topical Conference on Shock Waves in Condensed Matter, American Institute of Physics, no. 78, pp. 486-490, 1981.
11. S. P. Marsh, *LANL Shock Hugoniot Data*, University of California Press, Berkeley, California, 1980.