INITIATION OF SECONDARY EXPLOSIVES MEASURED USING EMBEDDED ELECTROMAGNETIC GAUGES

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Abstract. There is considerable evidence that secondary explosive materials having a relatively large (10-12%) proportion of HTPB binder do not exhibit DDT under cook-off. However, the understanding of the mechanisms controlling the growth of reaction in such experiments is incomplete. Most importantly, it is not known whether a mechanistic reason exists to preclude DDT; it is possible that existing techniques to explore cook-off simply do not offer the correct conditions to allow DDT to occur. We present experiments in which impacts were made against a RDX/HTPB PBX using a single-stage light gas gun. Electromagnetic particle velocity gauges were embedded within the targets at different distances from the impact face to record the onset of reaction, and in some cases detonation. These experiments were also performed against RDX/TNT targets. The time-resolved particle velocity histories have allowed comparison of some of the factors governing growth of reaction, and have provided run-to-detonation distance data for different impact stresses.

Keywords: Ignition and growth, PBX, particle velocity gauge, shock initiation.
PACS: 07.07.Df, 06.06-Ei, 47.40-Nm, 82.40-Fp.

INTRODUCTION

The particle velocity technique using embedded gauges has been extensively used over the past decades to explore the initiation and subsequent growth of reaction in energetic materials. In this technique conductors, embedded in a material that is subjected to shock loading, will acquire the local particle velocity. This can be measured by arranging a steady magnetic field so that a current is induced in the moving conductors. Early work [1-3] focused on the measurement of steady detonations, while more recently [4-7] interest has shifted to the initiation of explosives by gas-gun driven flyers. More recent work [9,10] has developed this technique using the 50mm single-stage gas gun at Shrivenham [8], and has included some characterization of the type of RDX/HTPB PBX that is currently of interest in the UK.

In this work we have refined our technique further in terms of target preparation and generation of the magnetic field, we have made improvements to measurement accuracy, and we have eased the experimental load in carrying out this type of experiment. Firings have been made in which RDX/TNT and RDX/HTPB charges were initiated, and the run-to-detonation distances have been measured. There appears to be superficially good agreement between our data and that for Composition B-3, but there remain unexplained details in the particle velocity histories we have recorded that demand further study.

EXPERIMENTAL PROCEDURE

The particle velocity gauges were of the Vorthman type [4], and followed the design

described in [9], having seven Lagrangian elements varying in width from 13mm to 7mm, and a single 'shock tracker'. The gauge arrays were etched from a flexible laminate of copper and polyimide, 87μm thick. The variation in length of the Lagrangian elements was no more than 0.3%.

The gauges were encapsulated with two sheets of Mylar, bonded to the gauge using a low-viscosity epoxy adhesive to avoid premature loss of signals by the ionization from the incipient detonation. In early experiments, the encapsulating material was 50μm thick, yielding a gauge package thickness measured to be 185μm. In later experiments the encapsulating material was 25μm thick, yielding a gauge package thickness of 140μm.

The targets were all manufactured in two separate slabs, with one face angled to allow the gauge to be cemented between them at an angle to the impact face. The angled arrangement meant that an unobstructed portion of the target was presented to each gauge element along the impact axis. For these experiments the gauge angle was chosen to be 60º to give a large depth over which the target was instrumented.

The RDX/TNT target components were cast from a single batch into a preheated mould that accurately defined the impact face and gauge mounting faces. The sample densities were measured using the Archimedes method, the RDX/TNT targets being 1.66±0.02g/cc. and the PBX 1.58±0.06g/cc. The PBX targets were cut from a single block, and lapped by hand to final dimensions. Additional characterization data are found in [11]. The angle of the gauge plane was measured with a vernier gauge to be 60±0.25º for all parts.

The gauges were assembled onto one half of the target using an alignment jig and microscope, to an angular tolerance of ±2mrad with respect to the impact face. A low viscosity epoxy adhesive was used to join the two target components together. Each target was covered by a 1mm thick PMMA plate to aid mounting into the gun. The mounting alignment for this gun is typically 1.25mrad.

The magnetic field was generated using a pair of electromagnets, energized at the moment of the experiment by switching a high-current power supply. In early experiments, two coils in the classical air-spaced Helmholtz arrangement were used, as described in [9]. While the results were good, several practical drawbacks were found: (a) the coils were destroyed on every experiment and new ones had to be made each time; and (b) to obtain a useful flux density in the target zone, the coils were driven with ~10kW power, leading to rapid Joule heating, and hence making calibration and testing of the coils difficult.

The later experiments were made using a pair of coils embedded in a steel and aluminium housing. The electromagnet geometry was designed using a commercial finite element code, in an iterative process that aimed to achieve high field strength and low supply power. The final design generated a field measured to be 110±2.0mT in a zone 20x20x20mm, centred on the axis of the gun. This was achieved using a 24V DC battery bank, delivering 60A. A thermocouple embedded in one of the coils measured a rate increase of temperature of $0.2^{o}Cs^{-1}$, and a measured rate of decrease in field strength of $0.1mTs^{-1}$. A flux meter was used to map the magnetic flux density, corroborated with measurement of the coil current using a clamp meter.

The eight sensing elements in the gauge package were connected by separate RG174 coaxial cables to two 4-channel oscilloscopes of 1Ghz bandwidth, sampling at 1.6ns per point. The interconnecting cables were chosen to be impedance matched throughout. At a particle velocity of $1kms^{-1}$, the longest Lagrangian element, (13mm wide) would be expected to give a signal of ~1.5V.

RESULTS AND DISCUSSION

It can be seen in Fig. 1 that the particle velocity on successive gauge elements increases, indicating the onset of reaction in the specimen.

The gross form of the record is consistent with expectation, but there are details that require further explanation. In particular, the particle velocity on each gauge overshoots after the initial rise, and this prevents analysis of the material flow immediately behind the shock. The rise times for the initial particle velocity excursion are consistent with an impact alignment of 2.5mrad. In this

experiment, the run to detonation occurs close to the last Lagrangian element at 13.2mm from the impact face.

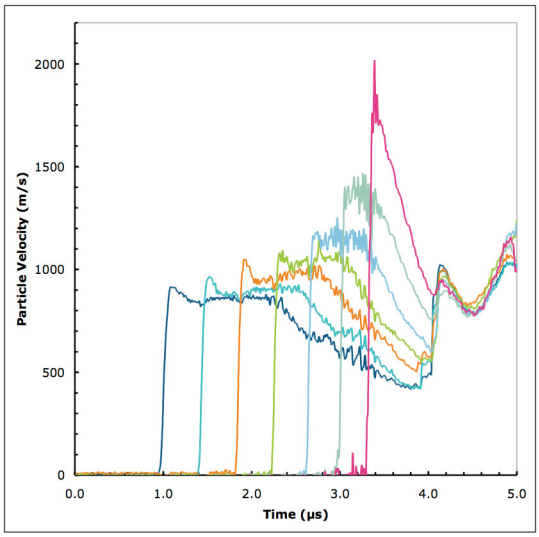

Figure 1. A typical particle velocity history for the PBX target. σ = 5.1±0.25GPa. Gauge elements at 2.8, 4.5, 6.3, 8.0, 9.7, 11.5, 13.2mm from the impact face. Detonation occurs between the gauges at 11.5 and 13.2mm.

The shock velocity can be obtained by linear fitting either to the shock tracker data (Fig. 2) or to the arrival times at the Lagrangian elements. The measured particle velocity, at the plateau after the initial rise and overshoot, can then be used to plot the unreacted Hugoniot for the specimen, in U_s-U_p space as shown in Fig. 3.

The linear fits to the shock tracker arrival times were used to obtain run distances to detonation for each experiment as noted in Fig. 2. The known Hugoniots [10,11] were used to obtain impact stress given the (linear) shock velocity prior to breakout of detonation. These yielded the plot shown in Fig. 4 for both compositions.

It can be seen from the plot in Fig. 4 that the RDX/TNT in this study has similar initiation properties to Composition B-3, over the range of impact stresses tested. The slight decrease in sensitivity compared with Composition B-3 is attributed to the use of HMX-free RDX in our material.

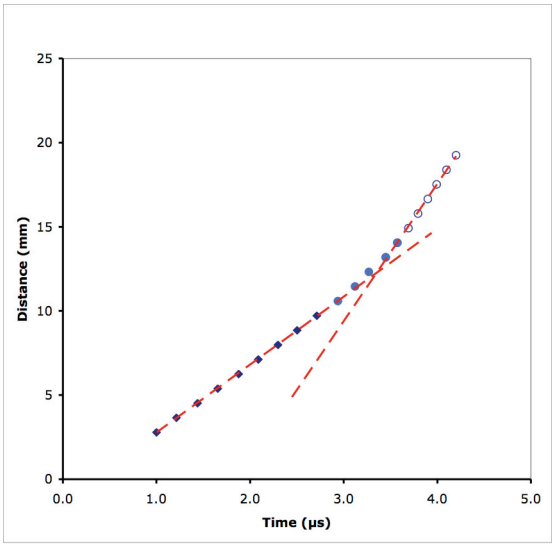

Figure 2. Shock tracker data for the shot shown in Figure 2. The linear fits give U_s = 4.03±0.1mm μs^{-1}, D = 8.16±0.15 mm μs^{-1}. The transition between the two linear portions appears to be gradual. The crossing point for the linear fits suggests breakout of detonation at 12.4mm.

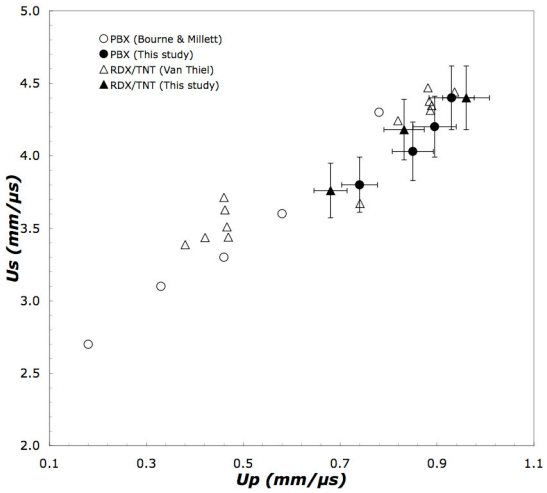

Figure 3. Hugoniot in U_s-U_p space for PBX (circles) and RDX/TNT (triangles). Literature data (open symbols) shown for comparison. U_p taken from the Lagrangian element closest to the impact face; U_s derived from the shock arrival X-T plots, e.g. Figure 3.

The PBX composition is less sensitive than RDX/TNT, and a linear fit through the PBX data on the Pop-plot has a shallower slope compared to

RDX/TNT. Hence, for low-stress impacts the run distance is longer. Extrapolation of the trend for the PBX upwards implies that at ~7GPa the run distance to detonation for the PBX and for RDX/TNT will be the same. It should be noted, however, that there are presently few data points in this study and confirmation of this trend must await further experiments.

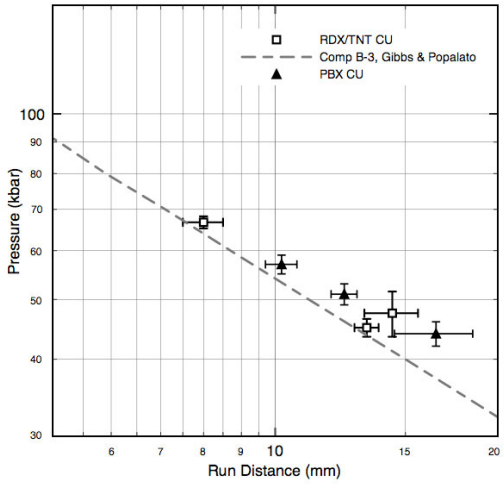

Figure 4. Pop-plot of impact pressure vs. run distance to detonation for all experiments. Literature data (Van Thiel) for Comp B-3 are given for comparison.

CONCLUSIONS

The embedded electromagnetic gauge technique has been implemented with reasonable success. The gross features of the initiation of the two secondary explosives have been captured, and there is good correspondence between literature data and the data from this study in both U_s-U_p Hugoniot measurement and 'Pop-plot' measurement.

There are unexplained details in many of the experimental records, which obscure important features during the particle velocity history. In particular, the overshoots noted in Fig. 1 are apparent to some extent on all records. These are attributed to the shock impedance mismatch between the gauge package and the test specimen: a detailed study, following Cau [12], is proposed to examine these features in greater depth.

ACKNOWLEDGEMENTS

The authors would like to thank Prof. Neil Bourne, Miss Sally Gaulter, Dr William Proud and Dr Ron Hollands for their valuable advice.

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2009-12-31
American Institute of Physics (AIP)
https://doi.org/10.1063/1.3295120
Stennett C, Cooper GA, Hazell PJ, Appleby-Thomas GJ. (2009) Initiation of secondary explosives measured using embedded electromagnetic gauges. AIP Confrence Proceedings, Volume 1195, Issue 1, December 2009, pp. 267-270

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