Observation of sub-detonation response in confined high density HMX based PBXs

M D Cook\(^1\), A D Wood\(^1\), P R Ottley\(^1\) and P J Cheese\(^2\)

\(^1\)QinetiQ Ltd, MoD Fort Halstead, Sevenoaks, Kent TN14 7BP, England
\(^2\)DE&S, MoD, Abbey Wood, Bristol BS34 8JH, England.

E-mail: mdcook@qinetiq.com

Abstract. This paper describes experiments and modelling aimed at understanding the behaviour of highly loaded (90%-95%) pressed HMX-based PBX compositions, when subjected to shock compression and ignition, by means of a propellant donor charge, under confinement. Such tests are routinely carried out in the UK on new formulations to determine their burn to violent reaction characteristics. The Bullseye propellant donor charge has been characterised in terms of pressure and temperature output. A range of tubes have been designed to examine the contribution of tube material properties (steel versus aluminium, 218.5 MPa) and to examine the effect of reduced confinement (120 MPa). For the reduced confinement scenario polycarbonate as well as steel and aluminium vessels have been designed which allow the reaction of the energetic material to be captured using a Phantom high-speed camera. In particular, tests carried out in the polycarbonate tubes have given a good insight of the processes occurring. Preliminary hydrocode modelling runs predicted an oscillating compressive wave in the explosive and considerable damage at either end of the explosive column. The latter leads to potential deconsolidation once the donor charge has burnt out allowing increased burning and violence.

1. Introduction

Globally there have been a number of research initiatives to understand Deflagration to Detonation Transition (DDT) and to develop small-scale tests that can screen out unsuitable explosive formulations. These are primarily based around closed bombs, tube type configurations [1], or burning of previously badly damaged fragmented material. In the latter test the damage is usually produced by throwing the test sample at a metal plate at relatively low velocity. This material is then recovered and burnt in a closed bomb and the pressure time history measured [2]. In closed bomb or tube tests the damage and ignition occur due to a donor propellant system that provides both mechanical deformation and ignition through heat conduction of the hot propellant gases onto the test material surface.

Similarly, modelling initiatives have been undertaken, but are non-predictive. The reasons for this are that DDT, especially in relation to weapon systems, is still poorly understood.

In the UK, small-scale tests referred to as the Tube Tests, are used to screen for DDT. The same tube design can be used in three variants: mini fuel-fire, electrically heated Cook-Off and internal ignition options. They have been successfully used to screen out energetic materials that are susceptible to DDT.
In this paper we discuss some recent experiments and modelling aimed at understanding the behaviour of highly loaded (90%-95%) pressed HMX-based PBX compositions in high and low confinement Tube Test designs.

2. UK Internal Ignition Tube Test
The UK internal ignition tube test comprises a cold drawn mild seamless steel tube with an i.d. 31.4 mm, 6 mm thick wall, sealed at both ends by means of two mild steel screw-on end caps. The tubes are 253.5 mm long and are designed such that they fail, due to excess pressure, in the middle rather than at the end caps. A 2.4 mm hole drilled in one end cap is used to accommodate the leads from an electric fuze-head. While the Cook-Off tubes are completely filled with energetic material, the internal ignition variant has a 21 mm deep cavity at one end to provide space for the propellant donor charge. While it is preferable to fill the energetic material directly into the tubes this is normally not possible and so a number of pellets are manufactured and these are pushed into the tubes by hand. There are five of these (46.5 mm long) for the internal ignition test and six 42 mm long for the Cook-Off tests.

![Figure 1: UK internal ignition tube test.](image)

The internal ignition version of the Tube Test (figure 1) employs 1.5 g of Bullseye propellant ignited by means of an electric fuze-head as the donor charge. After firing, the remains of the tube are collected together with any unconsumed energetic material. Both are weighed and the results recorded as a percentage of their original weights. The total number of steel fragments recovered is noted as is the contribution from the tube and end caps. From an assessment of the number of steel fragments produced, the violence is categorised according to the criteria shown in table 1.

| Reaction category | Reaction Description | Observation |
|-------------------|----------------------|-------------|
| 0                 | No reaction          | No mass loss |
| 0/1               | Burning / decomposition | No disruption of test vehicle |
| 1                 | Pressure burst due to burning / decomposition | Assembly ruptured but one fragment approximates to original weight |
| 2                 | Deflagration          | 2 to 9 body fragments |
| 3                 | Explosion             | 10 to 100 body fragments |
| 4                 | Detonation            | >100 test vehicle body fragments showing evidence of detonation |
3. Characterisation of current Tube Test
The pressure output of the propellant donor charge has been characterised. Three tubes were cast filled with an inert PBX stimulant consisting of 61% Melamine, 24% Barium Sulphate 7% HTPB and 8% DOS leaving a 21 mm deep gap. Modified end caps were designed and manufactured to accept a Kistler pressure gauge as well as the igniter wires. Peak pressures measured ranged from 75.9 MPa to 87.1 MPa in a series of fifteen tests. There was also some noticeable variation in the ignition time and the area under the pressure time curve.

Optical pyrometry was used to probe the reaction temperature of the propellant confined within the tube test. The approach was to use a fast time response gated spectroscope, in conjunction with photodiodes to provide triggering upon the start of reaction. Addition of 0.15 g of graphite to the Bullseye enhanced the emissivity of the reaction products. The powder had the dual effect of enhancing black-body emission and absorbing light from the spectral features. By this means the peak temperature was determined to be 2514 K ± 4 K.

4. Modelling the Tube Test
Some scoping studies using the DYNA2D hydrocode [3] have been performed. These indicated that the propellant donor charge induced oscillating pressure waves in the explosive test material. Furthermore, these studies suggested that damage would be predicted to occur at both ends of the stack of explosive test pellets.

5. Low Confinement Tube Designs
The standard steel tube was calculated to have a burst pressure of 218.5 MPa. An aluminium tube was designed that had the same burst pressure along with steel, aluminium and polycarbonate tubes that had a reduced burst pressure of 120 MPa. These had wall thicknesses of 8.67 mm, 3.53 mm, 5.21 mm and 17.34 mm for thick walled aluminium, thin walled steel, thin walled aluminium and polycarbonate tubes respectively.

The polycarbonate tube (figure 2), being transparent, allowed the reaction to be observed using high-speed photography. The tube was designed around the same internal dimensions as the standard tube. A square configuration was adopted such that the outer walls were flat in order to reduce optical distortion. The design also employs steel capping plates rather than screw on end caps. The capping plates were designed with ‘O’ rings and held in place by means of tie bars placed though holes in each of the four corners of both plates. A small hole with identical dimensions to that used in the end cap of the current tube test was also made in the plate that houses the Bullseye propellant donor charge.

![Figure 2: Low confinement (120 MPa) polycarbonate tube.](image-url)
6. Experimental

Three explosive compositions were used in this study: 95% HMX / 5% Viton; 92% HMX / 6% DOA / 2% HyTemp; 90% HMX / 10% Viton. In a few experiments half-length pellets were employed. The pellets were carefully loaded into the tubes along with the Bullseye propellant donor charge. Most of the tubes were pre-fitted with two strain gauges on the outer surface.

The tube ready to fire was taken to the bomb chamber and placed horizontally on a pre-manufactured wooden rig that had two mirrors place at 45° above and below to the rear of the tube so that the rear and sides of the tube could also be observed. Flash bulbs mounted in the rig allowed for observation of the event using a Phantom 7.10 high-speed camera.

After the firing, the remains of the assembly were collected, together with any unconsumed explosive. Both items were weighed and recorded as a percentage of their original weights. The total number of fragments recovered was recorded along with the number of fragments produced by the tube representing the body of the assembly. All fragments and explosive remains were photographed.

In the normal test a sequence of ten repeat firings are carried out to provide some statistical data. In the research firings performed here only three repeats were typically carried out.

7. Results

As expected, the 95% HMX / 5% Viton produced the most violent reactions. The 90% HMX / 10% Viton composition also gave very violent reactions in the high-confinement metal tubes, although the reaction was considerably less violent in the lower confinement tubes. In contrast the 95% HMX / 5% Viton composition gave the appearance of detonations (based on tube fragmentation) in all tube configurations except for the thin walled aluminium ones which showed type 2 reactions.

The 92% HMX / 6% DOA / 2% HyTemp formulation gave mild reactions in all the tube tests carried out here. This formulation has more HMX (92%) than the 90% HMX / 10% Viton composition; the difference between these two being the binder system and the mechanical properties rather than the HMX content.

The high-speed video records of these tests were quite revealing, especially with the polycarbonate tubes. Close examination of the polycarbonate Phantom camera records indicated that the following events occurred during the firings.

On firing, the Bullseye propellant donor charge was seen to ignite and burn brightly. It burns for approximately 2 ms. The burning Bullseye propellant compresses the acceptor pellets. This is most evident with the HyTemp formulation, a softer composition that is forced against the tube walls creating a change in optical appearance. Once a critical pressure has been reached the flame passes down the side of the acceptor pellets. Once the flame reaches the bottom it is reflected back along the tube and oscillates back and forth.

In most cases the pellets are observed to ignite on their outer surface. The HyTemp formulation charges showed less inclination to burn. Bright lines are seen periodically between the pellets indicating increased reaction as pressure waves oscillate back and forth along the tube. Once the pressure from the donor charge drops, the pellets appear to re-exert and, in some tests with the 90% HMX and 95% HMX / Viton formulations move along the tube to the donor end. With these two formulations the drop in pressure is clearly associated with rapid growth in the observed burning presumably through increased burning surface created as the result of deconsolidation and fragmentation of the pellets. Increased burning is often observed at both extremes of the stack of test pellets. If there is sufficient fragmentation, then ignition of the pellets leads to rapid burning, often from both ends of the pellet stack at the same time. If there is sufficient confinement, the burning appears to accelerate. The lower confinement tubes lead to early tube rupture and quenching of reaction. A typical sequence of events for the 95% HMX / Viton formulation is shown in figure 3. The frames are arranged starting from top left to right. The burning Bullseye propellant donor charge can be clearly seen in the middle top frame just as the flame pushes past the pellet stack along the tube wall. The bright vertical lines seen in frames 3-5 are thought to be due to the oscillating pressure
waves in the tube. The last frame shows accelerated reaction preferentially to the right of the tube at the end furthest from the Bullseye propellant donor charge. At a later time reaction also grows at the other end of the pellet stack towards the right. In the case of the metal tubes it appears that most show case deformation starting closer to the Bullseye and progressing towards the far end of the tube.

![Figure 3: Sequence of frames taken from the high-speed video record of a firing of the 95% HMX / Viton formulation in a low confinement (120 MPa) polycarbonate tube.](image)

The Phantom camera records were also used to estimate the velocity of the burning reaction especially in the most violent reactions. These measurements revealed that reaction velocity was less that 3 km/s and were more akin to accelerating deflagration than a high-order detonation. This is in contrast to the fragmentation evidence (small fragments and extensive damage to the end-caps) which suggested a classic detonation had occurred. Further experiments are planned to deliberately detonate the explosive in order to produce tube fragmentation patterns to help refine the sentencing criteria of the test.

8. Conclusions
High-speed photography coupled with transparent polycarbonate tubes has successfully been used to study the processes occurring in the internal ignition tube test. Examination of these records suggests that DDT does not occur even in the most violent events in the tube test. The results reported here have gone a long way to help understand the mechanisms operating in weapon level tests.

Acknowledgments
This work was carried out as part of the UK-Energetics research programme from the Dstl Programme and Delivery Directorate of the Ministry of Defence.

References
[1] Price D and Wehner, J F 1965 The Transition from Burning to Detonation in Cast Explosives *Combustion and Flame* 9 p73-78.
[2] Sholtes J H G and van der Meer B J 1997 The construction of the friability test at TNO-PML *TNO report* PML1996-A58.
[3] Whirley R G and Engelmann B E DYNA2D A nonlinear explicit two-dimensional finite element code for solid mechanics *Lawrence Livermore National Laboratory Tech. Rep.* UCRL-MA-110630.