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Development of tuneable effects warheads

Mark REYNOLDS *, William HUNTINGTON-THRESHER

QinetiQ, Fort Halstead, Sevenoaks, Kent TN14 7BP, UK

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Abstract

The tuneable effects concept is aimed at achieving selectable blast and fragmentation output, to enable one charge to be used in different scenarios requiring different levels of blast and fragmentation lethality. It is a concept QinetiQ has been developing for an energetic fill consisting of three principal components arranged in co-axial layers, two explosive layers separated by a mitigating but reactive layer. The concept was originally designed to operate in two modes, a low output mode which only detonates the central core of high explosive and a high output mode which detonated both the central core and outer layer of the explosive. Two charge case designs where manufactured and tested; one of these designs showed a reduction in blast and fragment velocities of ~33% and ~20%, respectively, in the low output mode.

Keywords: Tuneable effects; Multiple effects; Blast; Fragmentation; Hydrocode; Modelling; Trial

1. Introduction

The tuneable effects warhead concept is based on QinetiQ patented [1] technology, previously explored using bare explosive charges [2]. This work showed significant differences in peak blast pressures between two detonation modes (35%) while maintaining quasi-static pressure. The study reported here looked at developing a metal cased variant with the aim to demonstrate a tuneable fragmentation output, whilst maintaining the demonstrated blast performance.

This next step for the concept was to test it in a more representative configuration generating fragments and blast. To ensure the exploitability and the relevance of the study, the warhead was designed to generate fragments with a lethal effect in the high mode.

2. Tuneable warhead concept

The concept consists of an energetic fill constructed from three principal components arranged in co-axial layers (Fig. 1), namely:

1) High-performance High Explosive (HE) (HMX/PB – Polymer Binder)
2) Reactive, but non-detonable composition (aluminium powder loaded rubber)
3) Highly-aluminised explosive composition (RDX/Al/PB)

Two modes are available:

- Mode 1 (lower incident pressure) – initiate central charge (1) only,
- Mode 2 (higher incident pressure) – initiate both charges (1) and (3)

3. Case design

Both analytical codes and QinetiQ's Eulerian hydrocode GRIM were used to help develop two possible designs for the steel case. The cased designs were required to perforate a 5 mm steel target when operating in the high mode. Simulations were also used to predict the theoretical difference in case fragmentation between the low and high modes. Fragmentation, driven by external groove designs, was explored together with a more novel option combining a 3D printed plastic insert to initiate internal fracture circumferentially around the case, with axial external grooves.

The diameter and length of the charge were kept at the dimensions of the previous uncased study [2], the compositions of the energetic layers were also kept nominally the same.

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* Corresponding author. Tel.: +44 1959514911.

E-mail address: mwreynolds@qinetiq.com (M. REYNOLDS).

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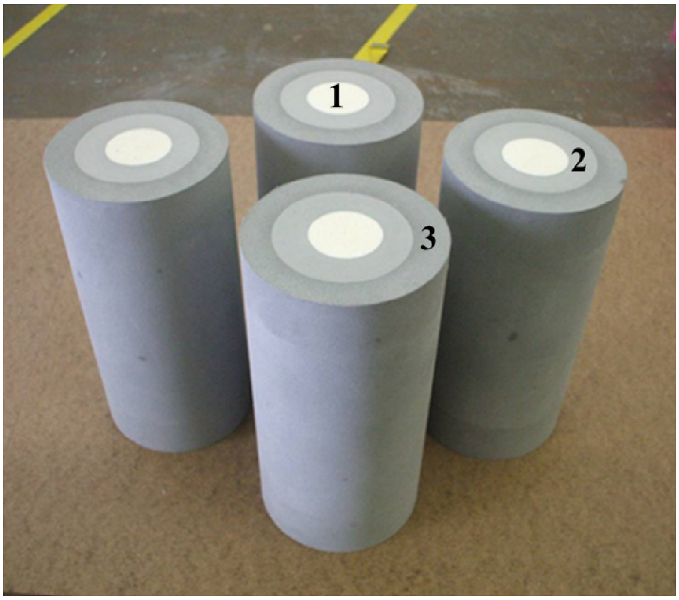

Fig. 1. Tuneable effects charges.

4. Split-X and hydrocode modelling

The design study applied Split-X to calculate the required steel case thickness to perforate a 5 mm steel plate in the high mode. Split-X [3] is an analytical code for the assessment of fragmenting warheads. Given the functionality of Split-X, the explosive, detonating in the mode, was modelled as a single cylinder with an inert surround. Given the available explosive mass, the assessment indicated that a case thickness of 10 mm with defined fragment sizes (approximately 10 mm cubes) was required to perforate the plate. The case steel selected was EN24 condition W. It was chosen based on the expected strength and ductility properties preferred for the case.

Hydrocode modelling with QinetiQ's Eulerian code GRIM was then applied to assess design options to control fragmentation and to assess the differences between the two detonation modes. The high mode was modelled with the detonation of both explosive components. The low mode was modelled with only the inner core of explosive detonating. The non-detonating components were modelled as inert throughout the timescales of detonation and initial fragment flight.

The typical arrangement for the GRIM hydrocode simulations is shown in Fig. 2. The central core of PBXN110 was 35 mm in diameter, the annulus of HTPB-Al was 15 mm thick and the next annulus of PBXN109 was 15 mm thick. This gave a total explosive diameter of 95 mm. The length was 200 mm.

For constitutive models to describe metals, the physically-based constitutive model due to Armstrong and Zerilli and modified by Goldthorpe et al. [4], Equation 1, is the preferred model used by QinetiQ. The Body Centred Cubic (BCC) form of the equation, relevant to the metals (Steel) in this study, is shown.

$$Y = C_0 + C_1 e^{(-C_3T + C_4T\log\dot{\varepsilon})} + C_5\varepsilon_p^n(a_1 - a_2T) \tag{1}$$

In this equation Y is the flow stress, T is the temperature, $\dot{\varepsilon}$ is the strain rate, and ε_P is the plastic strain, with C_1 through C_5, n and a_1 and a_2, which describe the temperature dependence of the shear modulus, constants derived from the characterisation tests.

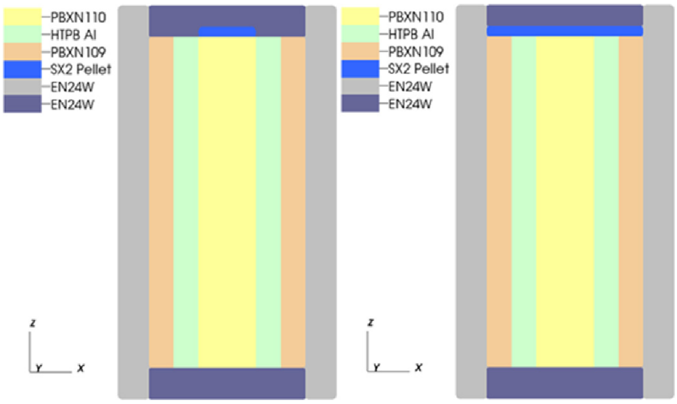

Fig. 2. GRIM model setup left – low mode, right – high mode.

As part of the drive to develop a system of physically based material models, Goldthorpe developed a path dependent ductile failure model [5]. The QinetiQ algorithm used in the code is Equation 2

$$S = 0.67\int_0^{\varepsilon_p} e^{\left[1.5\sigma_n - 0.04\sigma_n^{-1.5}\right]d\varepsilon_p} + A_s\gamma \tag{2}$$

In this equation S is the measure of ductile deformation/damage, σ_n is the stress state (pressure/stress) and γ is the shear strain with A_s derived from characterisation tests. The material fails when S reaches S_F, which was also derived from characterisation tests.

The parameters for the EN24 W condition steel are listed in Table 1.

The polymer composite materials, aluminised HTPB and PBXN109, were both represented with tabular equations of state, and for PBXN109 the QinetiQ Porter-Gould constitutive model [6]. Table 2 lists the parameters, and the initial moduli are provided for the dynamic regime of interest (i.e. in an unrelaxed condition).

The three explosive materials were modelled using JWL (Jones, Wilkins and Lee) equations of state; the parameters applied are listed in Table 3.

It was acknowledged that a highly aluminised outer layer would have a lower brisance in comparison to non-aluminised compositions. The consequence was that case fracture would

Table 1
EN24 W condition constitutive data.

Parameter	Value	Parameter	Value
C_0	790.4 MPa	n	0.65
C_1	950.0 MPa	a_1	1.13
C_3	0.0052 K^{-1}	a_2	0.000445 K^{-1}
C_4	0.00026 K^{-1}	S_F	1.09
C_5	715.0 MPa	A_S	2.0