PERFORMANCE OF FOX-7 (1,1-DIAMINO-2,2-DINITROETHYLENE) IN SHAPED CHARGE APPLICATIONS

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The use of insensitive munition (IM) becomes more and more important to increase the safety of weapon platforms, transportation, storage and munition handling. One way to obtain IM-properties is to use a low sensitive secondary high-explosive (HE) in the warhead.
The FOI-developed low sensitive HE FOX-7 (1,1-diamino-2,2-dinitroethylene, also denoted DADE or DADNE) is an interesting candidate for replacing commonly used more sensitive explosives such as Comp B.
In this paper the performance of FOX-7 compared to hexotol (Comp B) in shaped charge applications are presented. The initiation ability by a standard booster charge and the propagation of the resulting detonation front in a cylindrical charge were studied. The jet characteristics were compared using a high precision shaped charge. The jet straightness and velocity as well as the fragmentation time were evaluated. Finally, the jet penetration capabilities were measured. In almost all aspects the FOX-7 charge improved upon the hexotol baseline charge.

INTRODUCTION

The use of insensitive munition (IM) becomes more and more important to increase the safety of weapon platforms, transportation, storage and munition handling. One way to obtain IM-properties is to use a low sensitive secondary high explosive (HE) in the warhead. This article describes ongoing work at FOI to evaluate the performance of the HE FOX-7 (1,1-diamino-2,2-dinitroethylene, also denoted DADE or DADNE) in shaped charge applications. FOX-7 is a low sensitive HE molecule with a theoretical performance slightly better than Comp B [1].

The performance of a shaped charge warhead is very sensitive to imperfections on all of its components, including the initiation train, the liner, the casing and the HE. The shaped charge tested in our study uses a high quality liner material and a well-proven initiation train. Here, we want to investigate whether an insensitive explosive (in this case FOX-7) can be reliably initiated, and accomplish a uniform and symmetric detonation wave and how well it behaves as a shaped charge main HE-filler.

In the tests an isostatically pressed formulation composed of FOX-7/wax was used. As baseline an identical shaped charge was used, but filled with isostatically pressed Swedish hexotol (composition identical to Comp B).

The tests were carried out in three stages. Initially the initiation ability by a standard booster charge and the propagation of the resulting detonation front in a cylindrical charge were studied. FOX-7 showed a very good symmetry in the shock front arrival times, better than for hexotol. Then, the jet characteristics were compared using a high precision shaped charge. The jets were recorded using flash X-ray and computed radiography. Using image processing, the jet straightness and velocity as well as the fragmentation time were evaluated. Finally, the jet penetration capabilities in steel armour plates at a stand-off distance of 500 mm were measured. In almost all aspects the FOX-7 charge improved upon the hexotol baseline charge.

PROPERTIES OF THE HIGH-EXPLOSIVES

Granulates of waxed FOX-7 were provided by EURENCO Bofors AB. The nominal composition was 97.8 wt% FOX-7 and 2.2 wt% wax. The granulate was composed of 25% small and 75% large crystals. The mean particle sizes of the crystals before the wax coating were (according to the manufacturer), 27 μm and 300 μm. A SEM analysis showed that the granulate consisted of an agglomerate and that the particle sizes were probably reduced during the waxing procedure (see Figure 1). For the reference charge, a pressed fraction of hexotol (Bofors hexotol NSK03 lot 82001, 60 wt% RDX, 40 wt% TNT) was used which has the same composition as Comp B.

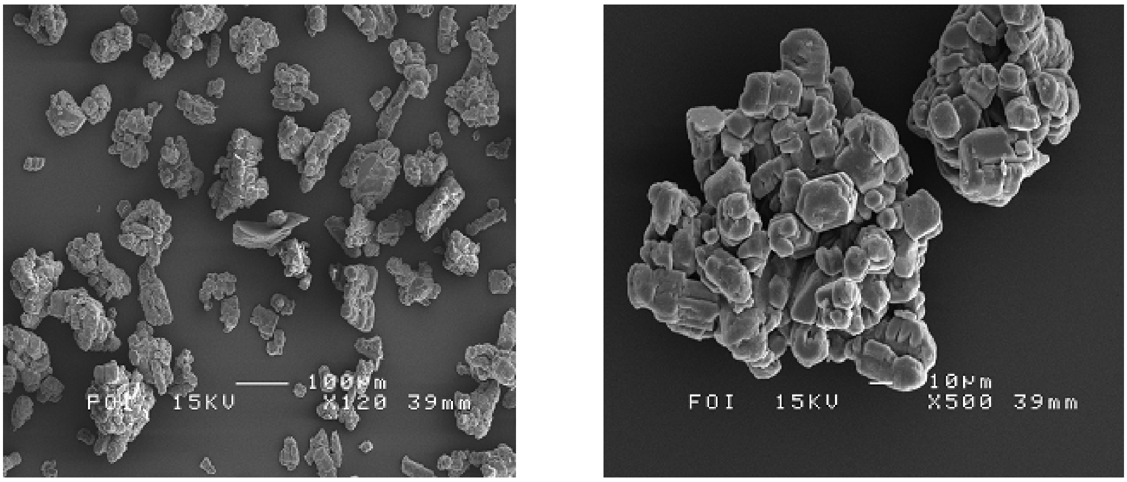

Figure 1. Granular of agglomerates consisting of waxed FOX-7 (left) and agglomerates magnified (right).

The waxed FOX-7 powder was examined with respect to its impact and friction sensitivity. The impact sensitivity was measured by the fallhammer method, ERL type 12B [2], falling weight 2.5 kg. The limit between reaction and no reaction was in the range 120-126 cm falling height, which is a very good result. The friction sensitivity was tested using the friction test BAM according to standard procedures [2]. No friction sensitivity could be measured even at the highest load (353 N), which shows that the powder is very insensitive to friction.

The theoretical and experimental performance of FOX-7 [1] is slightly better than for hexotol (Comp B) [3], see Table 1 (the densities are as given in the references, and not as the ones obtained here).

Table 1. Comparison of HE performances

HE	Density (g/cm³)	Detonation velocity (m/s)	CJ-pressure (GPa)	Detonation energy (kJ/cm³)
Hexotol	1.72	8000	29.5	8.5
FOX-7/wax	1.76	8300	27.9	8.7

DETONATION FRONT MEASUREMENTS

Two cylindrical charges were manufactured to investigate the symmetry of the detonation front as well as the initiation function using a well-tried standard booster charge. A measuring plate was put against one of the plane ends of the charge, opposite to the initiation point. A number of small holes (diameter 1.4 mm) were drilled in the plate where ionization gauges were glued. Figure 2 shows the positions of the gauges (left) and the charge design (right). Figure 3 shows the arrival times of the detonation front along the line given by gauges 9-15. The points have been fitted to hyperbolic curves (also shown in the figure). The FOX-7 curve showed very good symmetry though it was slightly displaced from the plate centre (probably due to none-exact centring of the plate). The mean deviations from the fitted curves were 0.4 ns for FOX-7 and 1.8 ns for hexotol. The deviations from mean arrival time around the circle given by gauges 1-8, which describe the rotation symmetry at the periphery, were also measured. The standard deviations were 2.8 ns for FOX-7 and 4.5 ns for hexotol. The maximal deviations (max(.)-min(.)) were 28 ns for FOX-7 and 39 ns for hexotol.

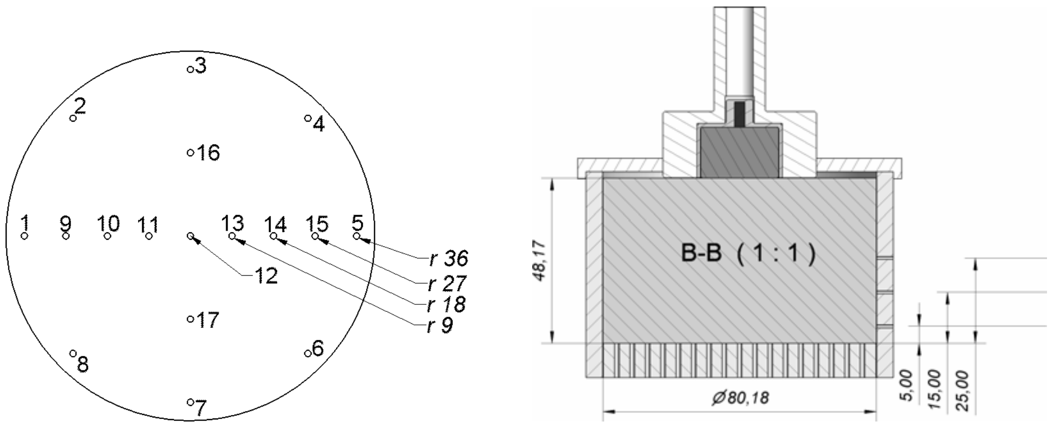

Figure 2. Experimental set-up for the detonation front arrival measurement.

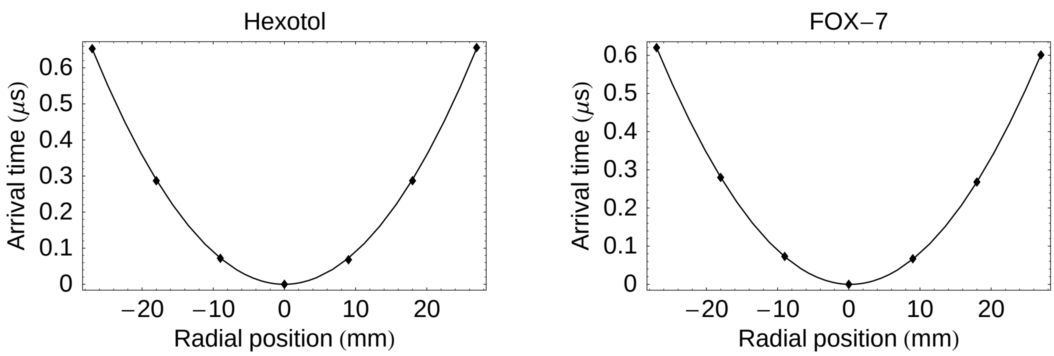

Figure 3. Detonation front arrival time along line 9-15.

SHAPED CHARGE PREPARATION AND EXPERIMENTAL SET-UP

Two shaped charges, one loaded with FOX-7/wax and one with hexotol, were fired. The design of the charges is shown in Figure 4 (left). The liners consisted of cold-pressed cupper cones manufactured by the Swiss company Aldorf. The charges were point initiated using a precision initiator consisting of pressed hexogen and a PBXN-5 plate, which in turn was initiated by a Nonel detonator. The charge densities were 1.70 g/cm³ for hexotol and 1.79 g/cm³ for FOX-7.

The charge was made accordingly: A rubber bag was filled with the explosives powder. In the bag, a press support was placed that had the same shape as the outer surface of the shaped charge liner. The bag with its content was air evacuated, sealed and isostatically pressed during one minute with a pressure of 250 MPa. The inner surface of the pressed charge was then glued to the liner with a thin layer of cyanoacrylate and machined on its outer surface to its final shape. Finally, it was put into and glued to an aluminum cover.

Figure 4 (right) shows the experimental set-up. The charge was placed in a hole of a protecting plate. The charge was fired against a pile of armour-plates (Armox 300S) at stand-off distance 1907 mm. Four (two 450 kV and two 150 kV) X-ray flashes were used to record the event at different times in different projections. The X-ray images were recorded in "imaging plates" using computed radiography [4], with a resolution of 50 µm/pixel. The time between the exposures was 30 µs for each projection.

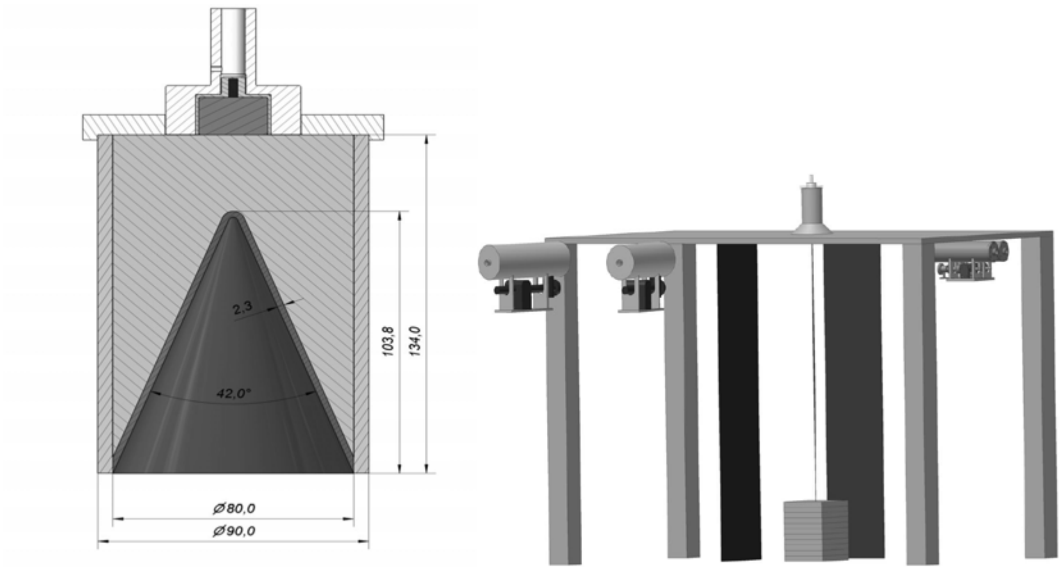

Figure 4. The charge geometry (left) and the experimental set-up for the X-ray flash recordings (right).

To examine the penetration ability at a more realistic stand-off, another test without X-ray was performed, where the charges were fired against a pile of 20 mm thick steel armour plates (Armox 300S) at stand-off distance 500 mm (6.25 charge diameters).

EXPERIMENTAL RESULTS

Because of the limited length of the imaging plates, four plates had to be put together to cover the whole length of the shaped charge jet. Before putting them together, each image was binarized by subtracting the original image from an estimated background illumination according to the methods described in [5]. The results are shown in Figures 5 and 6.

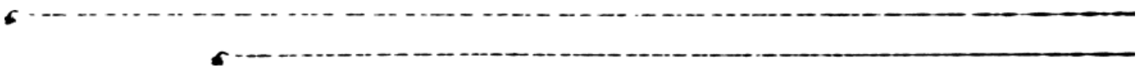

Figure 5. Jet from shaped charge with hexotol

Figure 6. Jet from shaped charge with FOX-7

The images were evaluated partly manually, partly using digital image processing. The manual evaluation was done by identifying identical fragments in the two exposures, and then measure their positions and the distances between them.

As a measure of the jet straightness (R) the average absolute deviation from the mean line was used, i.e.

$$R = \frac{1}{L}\int_0^L \left| z(x) - z_m(x) \right| dx , \qquad (1)$$

where L is the jet length, $z(x)$ is the center of gravity along the jet (x-axis) and $z_m(x)$ is the mean line. The mean line is found out by a least square fit of $z(x)$ to a straight line. Table 2 shows the straightness values for the jets. Figure 7 shows the jet velocities versus the accumulated lengths.

Table 2. Comparison of jet straightness (lower values indicate straighter jet)

HE	Jet straightness first exposure (mm)	Jet straightness second exposure (mm)
Hexotol	0.34	0.28
FOX-7	0.11	0.21

The fragmentation times obtained from the experiments did not differ significantly between FOX-7 and hexotol. It varied from 150 μs at the jet front portion to 200 μs at the trailing portion.

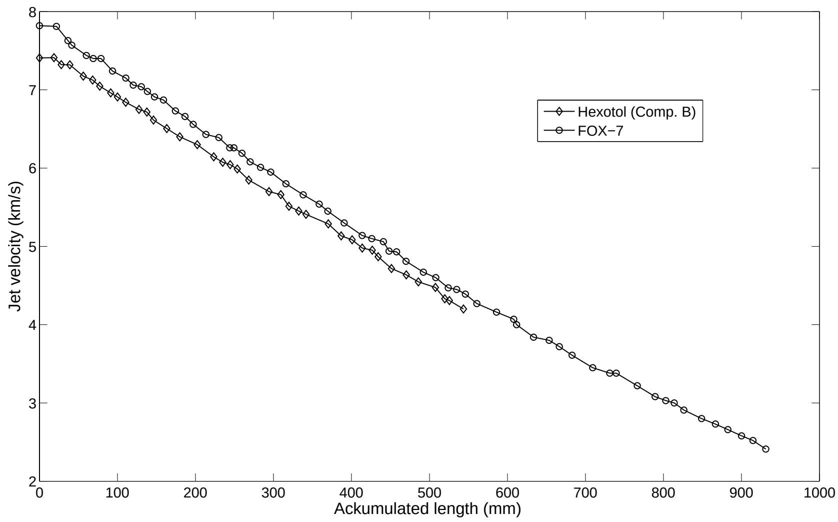

Figure 7. Jet velocities versus accumulated length

At the long stand-off distance, the hexotol loaded charge penetrated 265 mm armour, while the FOX-7 loaded charge penetrated 230 mm. However, at this long stand-off distance, the experimental variation is considerable. In the penetration test with a 500 mm stand-off distance, both charges penetrated 23 plates, i.e. 480 mm armour which equals six charge diameters. Calculation with the analytical penetration code HIPEN [6] using experimental jet data from the X-ray analysis showed similar results, though the calculated penetration ability for the FOX-7 charge was slightly better. It is not clear why the measured penetration capability did not show a corresponding increase in performance for the FOX-7 loaded charge.

CONCLUSIONS

Two HE, one conventional warhead filler (hexotol/Comp B) and one low sensitive HE (FOX-7), have been tested in order to compare their performances in shaped charge applications. The experimental results shows that in almost all aspects the FOX-7 charge improved upon the reference hexotol filled baseline charge.

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