**ISB 2011 – THE POTENTIAL OF FOX-7 IN IM MUNITION DESIGN**

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**Summary**— This paper describes research into the suitability of the explosive FOX-7 in the development of insensitive munitions. The analysis of experimental cylinder test data to generate a JWL equation of state and Gurney Energy is described and the results compared with other published data. The JWL and Gurney energy are then used in analytical and hydrocode simulations to assess FOX-7 performance in fragmenting and Slow Stretching Jet warheads and compared against other high performance explosives. The results of experiments to validate the simulations are presented and discussed.

**INTRODUCTION**

The modern battlefield requires the delivery of decisive military effects through the deployment of general munitions capable of delivering high volumes of fire and by complex weapons where precise effects are required. The energetic materials in these munitions are critical to effective operations. Weapon systems are required that meet Insensitive Munitions (IM) criteria, are legally compliant and have a long safe operational life. The achievement of these challenging requirements demands an understanding of the safety and performance implications of any changes to materials specifications.

The explosive 1,1-diamino 2,2-dinitro ethylene (FOX-7) has been examined by QinetiQ over a number of years as part of the on-going research into the provision of energetic materials with improved hazard characteristics. Research at Fort Halstead, Flower et al. [1] investigated a number of pressable PBX formulations based on FOX-7 and identified a number of candidates for exploitation, two of which are discussed in this paper.

The aim of the research reported in this paper, therefore, was to investigate the performance of the insensitive material FOX-7 in warhead applications.

**Technical Approach**

The technical approach adopted in the programme was based on an integration of small scale material testing/characterisation with numerical simulations and small scale experiments.

**FOX-7**

FOX-7 was first synthesized in 1998 by the FOA Defence Research Establishment (Sweden), Karlsson et al.[2]. Its explosive properties appear extremely favourable; in addition to its insensitive properties, the detonation velocity of mixtures of 80% FOX-7 plus binders are as high as Composition B. Similar work has been undertaken by QinetiQ under the UK-E research programme. Using cylinder test data and published results, representative models for the equation of state for a FOX-7 formulation, QRX080, containing 95% FOX-7 and 5% binder were constructed. The parameters generated were used to model the function and performance of FOX-7 in chemical energy (CE) and fragmentation systems.
EXPLOSIVE PRODUCTS MODEL

In order to predict the performance of FOX-7 in candidate warhead configurations an Equation of State is required to describe the ability of the detonation products to move solid materials, especially metals.

The Cylinder Test

The cylinder test was designed to address the problem of the transfer of explosive energy to a metal and to provide data to fit the Jones-Wilkins-Lee (JWL), Lee et al. [3].

Three cylinder tests were performed with QRX080 along with three independent measurements of the VoD on the same material. The detonation velocities recorded for the three tests were 8.23km.s\(^{-1}\), 8.22km.s\(^{-1}\) and 8.39km.s\(^{-1}\).

An advanced analysis of the experimental data using the fitting function, due to Hornberg [4], was used to describe the wall motion.

Equation of State

The empirically based JWL EoS was fitted to the data in conjunction with the thermo-chemistry code, CHEETAH, Fried et al.[5] used to estimate the CJ condition and then generate JWL parameters, as a starting point for fitting the experimental data for QRX080. This data was compared with other FOX-7 JWL information from the open literature, Trzcinski et al. [6] and Karlsson et al. [2].

FRAGMENTATION

The cylinder tests data was also used to calculate the Gurney velocity (2644 ± 40m.s\(^{-1}\)) and the Gurney energy (3496.5 ± 39.5J.g\(^{-1}\)). These values were used to investigate the ability of FOX-7 to propel pre-formed fragments as part of Multiple Effects Warhead (MEW) concept study, using the Split-X\(^{\text{®}}\) code [7] and the predictions were compared with PBXN-110.

The results showed that the PBXN-110 filling was predicted to yield a maximum fragment velocity of 1.018km.s\(^{-1}\), with the FOX-7 formulations ranging from 1.021km.s\(^{-1}\) to 1.053km.s\(^{-1}\), reflecting the variance of the Gurney parameters.

CE WARHEADS

Modelling

The charge design selected for the integrated simulation-experiment study was a 75 mm diameter SSI design with a with ‘tulip’ copper liner, centrally initiated with an aluminium cylindrical body.

The QinetiQ hydrocode GRIM was used to model the jets produced by this charge using the JWL EOS developed for QRX080 and the JWLs for FOX-7 variants due to Trzcinski et al. (95FOX7) and Karlsson et al., (KSN-FOX-7).

The jets produced by the various fillings at 300\(\mu\)s (simulation time) are represented using the pseudo-x-ray plotting capability in GRIM which allows direct comparison with experimental radiographs and shown in Figure 1. The figure also shows, for comparison, two experimental radiographs for the same charge filled with the high performance explosives LX14 and EDC1S.
respectively.

![Fig. 1. 75 mm SSJ pseudo-radiograph predictions for different fillings; actual radiographs shown on left for LX-14 and EDC1.](image)

### Experimental Firings

The predictions of the modelling study were validated experimentally in a small firing programme. The charges were fired vertically downwards into an array of four stacked Rolled Homogeneous Armour (RHA) blocks (of individual thickness 150mm). The stand-off distance was approximately twelve charge diameters (CDs), or 895 mm. The charge was supported by polystyrene foam. To capture data from the firings, both high speed photography and radiography were deployed. The penetration depth through the RHA array was also measured after each firing. Charges filled with PBXN-110 were used as a baseline for comparison.

![Fig. 15. Comparison of jets produced by PBXN-110 and QRX250 (FOX-7).](image)
CONCLUSIONS

This paper has described a research study to compare and contrast the performance of the FOX-7 with PBXN-110 and the high performance more sensitive explosives LX-14 and EDC1S in a SSJ shaped charge. In SSJ applications, FOX-7 formulations were predicted to offer slightly better performance than PBXN-110, but not as good as high powered more sensitive fillings such as EDC1S that are not IM fillings.

The paper has also presented results and analysis of cylinder test data for the 95% FOX-7 composition QRX080 to develop a JWL EoS for use in predictive numerical simulations and the calculation of the Gurney velocity and energy for FOX-7. The study has concluded that where the experimental data are considered up to V7 (before cylinder wall fracture is judged to occur), published models for FOX-7 fit the QRX080 early time data reasonably well. The JWL fit produced by CHEETAH does not fit the data as well as the published models.

The Gurney analysis predicts a very slight enhancement for QRX080 over PBXN-110, with the analytic code Split-X predicting higher fragment velocities for the FOX-7 based explosive. This trend would be expected for any fragmentation design currently or intended to use PBXN-110.

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