Transferable Explosive Formulations

Peter Bolton, Sara French, Peter Jenkins, Steve Miller, Lee Webb

AWE Aldermaston, Reading, RG7 4PR, United Kingdom

Email: peter.bolton@awe.co.uk or sara.french@awe.co.uk

Abstract

Transferable formulations offer significant safety advantages for IM systems as they may be used in out-of-line explosive trains, thus preventing accidental detonation of the booster from initiating the main charge explosive.

In this work, a liquid fluoropolymer was formulated with three different loadings of HMX and characterized to understand the effect of HMX concentration on critical diameter and detonation performance. The HMX loading was chosen to produce a range of paste-like properties. The liquid fluoropolymer was selected for these compositions as it offered improved thermal stability, volatility and toxicity over energetic liquids that are traditionally used for paste explosive applications.

Powder hazard tests show these formulations to have low sensitiveness. These formulations were tested in a track system to obtain an initial understanding of their critical diameters and detonation velocities. Furthermore, initiation train experiments were undertaken to test whether the formulations were capable of initiating a TATB based IHE material.

1. Introduction

The option of using a transferable explosive offers an improvement in safety properties for IM systems, for example as an out-of-line component of an explosive initiation train. A paste material would ideally be low viscosity with the ability to flow through small channels, but would not allow sedimentation of the filler. This paper details the formulation and testing of three explosive paste materials based on HMX and a liquid fluoropolymer. The fluoropolymer possesses advantageous thermal and toxicity properties over some energetic liquids which have been used in the past to produce paste explosives. It is a high density material and will also contribute, to some extent, to the energy output of the composition due to the fluorine content. This means a paste with better processability (i.e. higher binder loading) may be formulated with less compromise in performance.

2. Formulation

2.1 Polymer Selection

The thermal properties of a liquid fluoropolymer (details given in Table 1) were compared to that of an energetic liquid typically chosen for this application; K10 (a mixture of 2,4 and 2,6-dinitroethlybenzene, and 2,4,6-trinitroethylbenzene). As well as possessing lower toxicity, the fluoropolymer demonstrates better thermal stability despite having a slightly lower onset of decomposition (see Figure 1 and Table 2). Decomposition of the K10 is rapid compared to the fluoropolymer; after 15 hours at 120ºC the K10 shows a 100 % mass loss, compared to only 26 % of the fluoropolymer. Similarly, at 80 ºC K10 loses 44 % of its mass and the fluoropolymer

only 6 %. This is significant if the material were to experience higher temperatures during its service life.

Property	Value
Fluorine content	62%
Kinematic viscosity	85 cSt
Specific gravity	1.81 g/cm^3
Glass transition temperature	-110 ºC

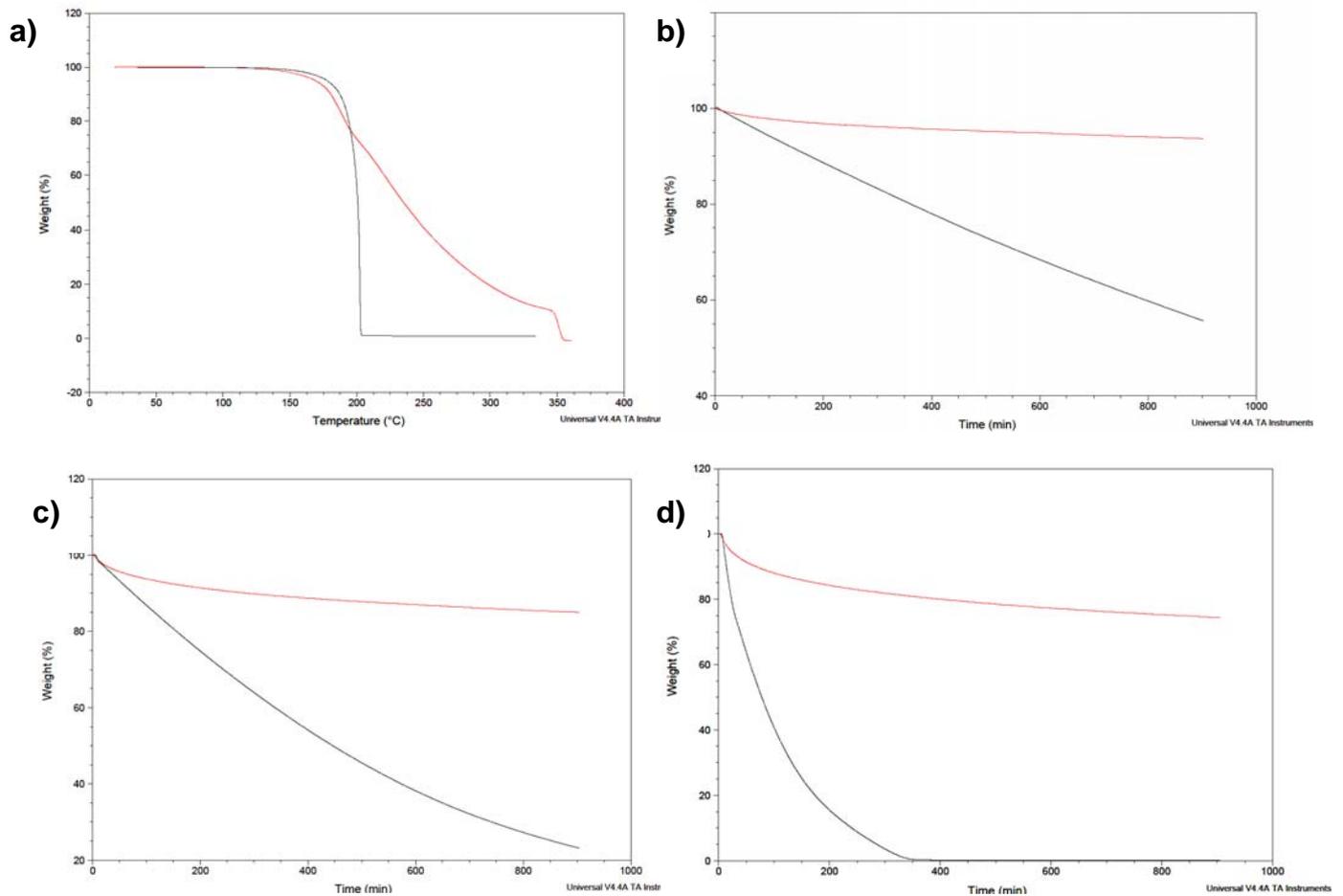**Table 1**: Properties of the fluoropolymer binder

Figure 1: Thermogravimetric data of K10 and the fluoropolymer (fluoropolymer in red); a) thermal ramp data; b) isothermal data at 80 ºC for 900 minutes; c) isothermal data at 100 ºC for 900 minutes; d) isothermal data at 120 ºC for 900 minutes

		Mass loss after 900 minutes (%)		
Material	Point of onset (ºC)	at 80 ºC	at 100 ºC	at 120 ºC
Fluoropolymer	175.9	6.3	15.0	25.6
K10	194.2	44.4	76.8	100.0

Table 2: Thermogravimetric data from the liquid fluoropolymer and K10

2.2 Mixing

HMX Type B (milled Bridgwater HMX) was dried prior to use. Three formulations **A** (65% filler by weight), **B** (70% filler) and **C** (75% filler) were prepared on a 500g scale using an IKA HKV1 (1 litre) planetary mixer. The mixing process was solventless and no vacuum was applied. The method is detailed in Table 3. The mix was periodically checked throughout the process. This involved reintroducing any powder adhering to the sides of the mixing bowl or the blades into the main mix to ensure homogeneity of the final product.

Stage	Mix Temp (ºC)	Blade Speed (rpm)	Mix Time (mins)
Addition of polymer			
Addition of HMX and mix		10	3
Raise temperature and mix	40	20	12
Scrape down and mix	40	20	15
Scrape down and mix	40	20	15

Table 3: Mixing method for the paste formulations

The physical appearances of the formulations are described as: **A** – 'slurry', **B** – 'paste-like' and **C** – 'clumpy'. Formulation **A** did not retain dimensional stability. This is undesirable as it could lead to sedimentation and phase separation over time. **B** exhibited good paste like properties and appeared low enough in viscosity that it could be suitable for filling small channels. Phase separation of the binder from the filler was not evident on application of force. **C** was noticeably higher in viscosity and whilst still malleable, would need to be processed under vacuum to ensure all air was rigorously removed.

2.3 Hazard Testing

Explosive powder hazard tests were carried on the formulations and the results demonstrate a high insensitiveness compared to neat HMX. Test results are displayed in Table 4.

Test	A	B	C
Mallet Friction	0 % all surfaces	0 % all surfaces	0 % all surfaces
Vacuum Stability (100 ºC)	pass	pass	pass
FoI (50 cap Rotter)	149	145	133
ESD	Ignitions at 4.5J; no ignitions at 0.45 J	Ignitions at 4.5J; no ignitions at 0.45 J	Ignitions at 4.5J; no ignitions at 0.45 J
Temperature of Ignition (ºC)	273.1	275.1	274.2

Table 4: Hazard test data of **A**, **B** and **C**

3. Characterisation

3.1 Failure Diameter

At a specific diameter, an explosive will be able to sustain a detonation, below this diameter too much energy is dissipated into the environment and the detonation wave fails to propagate. This is termed the critical diameter (also known as failure diameter). The degree of confinement on the explosive has an impact on the critical diameter, with greater confinement producing a system in which a smaller critical diameter is achievable. The determination of the critical diameter of the paste explosives was determined using a two stage test. The stage one test was designed to identify the approximate range in which the critical diameter resides; the stage two test was designed to be higher fidelity and provide a more accurate figure.

3.1.1 Stage 1 Critical Diameter Test

The test configuration consists of a Perspex track plate (Figure 2) containing a triangular cross-section (90 degree apex angle) groove with a receding or reducing depth from one end to the other. This was filled with approximately 6.8g of the test explosive and bolted to an aluminium witness plate. The explosive was initiated from the open end of the groove using a Reynolds RP-2 detonator. Detonation of the explosive track leaves an imprint on the witness plate. The cross sectional size of the explosive can be calculated from the length of the indent and the groove depth at point of failure.
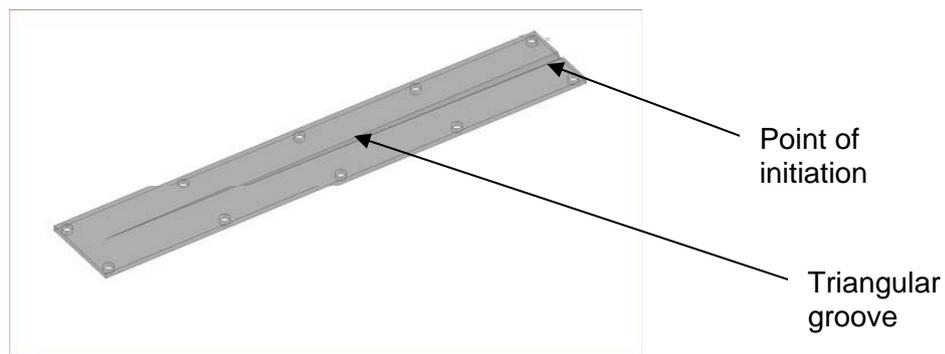

Figure 2: PMMA (Perspex) 'Receding Groove' Track Plate

Each explosive was tested in duplicate, the results are summarised in Table 5. **A** failed to initiate on both occasions; this was believed to be due to the poor consistency (slurry) of the paste. Both **B** and **C** were successfully initiated (Figure 3 show the witness plate after firing **C**) and average critical diameters of 2.30mm and 2.05mm were calculated for **B** and **C** respectively; the higher loaded formulation as expected being able to sustain detonation at a smaller diameter. These relatively large failure diameters are typical of HMX based materials.

Formulation	Failure Diameter (mm)	
	Shot 1	Shot 2
A	No result	
B	2.4	2.2
C	1.9	2.2

Table 5: Failure Diameters from Stage 1 Tests

Figure 3: Witness Plate from **C** Firing

3.1.2 Stage 2 Critical Diameter 'Multi-Column' Test

A more accurate determination of the critical diameter of the paste formulations was achieved using a test configuration based on that shown in Figure 4. In this experiment, columns of the test explosive are subjected to a detonation from a wider track of paste explosive that is greater than twice the critical diameter, as determined from the results of the Stage 1 test.
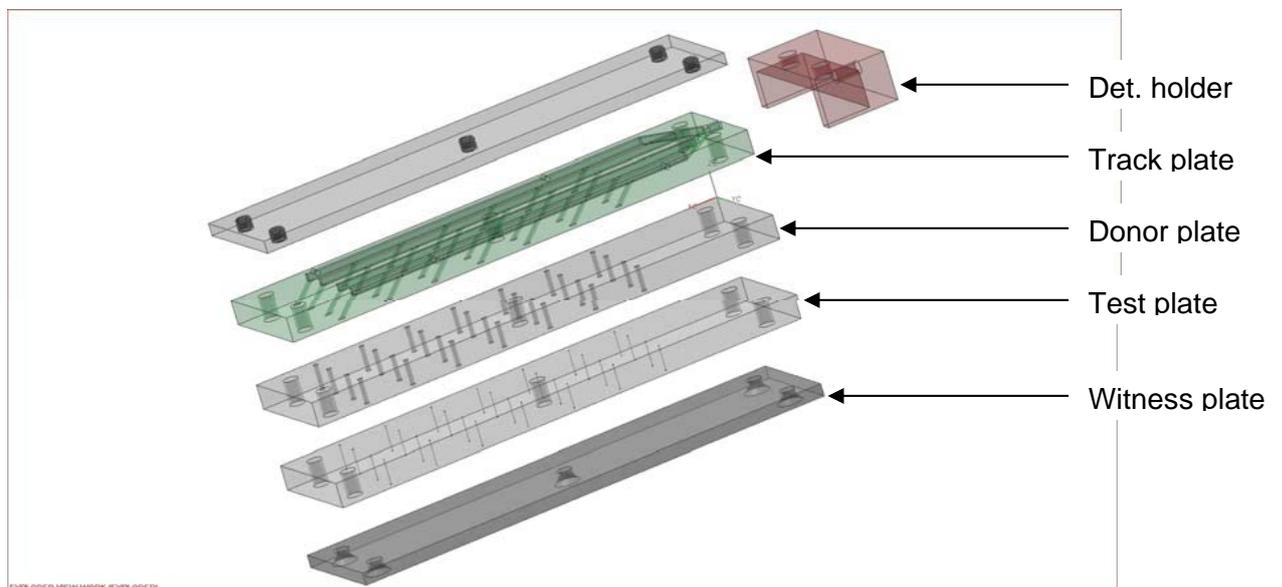

Figure 4: Stage 2 'Multi-Column' Test Assembly Design

The design consisted of a 5mm thick aluminium witness plate bolted to the bottom of the assembly to record dents from successful detonation propagation through the test columns. A 10mm thick PMMA (Perspex) test plate with various column diameters in the region of the nominal critical diameter determined from stage 1 and a 10mm thick donor plate with column diameter greater than twice the

critical diameter (equivalent diameter to the holes in the top track plate) were stacked on top of the base witness plate. Initiation of the top track plate was via an RP-2 detonator. Piezoelectric (time of arrival) probes were positioned in the top track plate (100mm apart) from which an indicative velocity of detonation was measured.

The results obtained from the Stage 2 test are summarised in Table 6 and indicate that the higher HMX loaded material has a slightly higher velocity of detonation and lower failure diameter, as expected. **B** showed evidence of detonation at 3.3mm and complete failure at 2.9mm or below (Figure 5). **C** indicated a failure diameter between 2.4 and 2.7mm, with complete failure below 2.4mm.

Formulation	Velocity of Detonation (mm/µs)	Failure Diameter (mm)
B	7.6	3.3
C	7.7	2.7 - 3

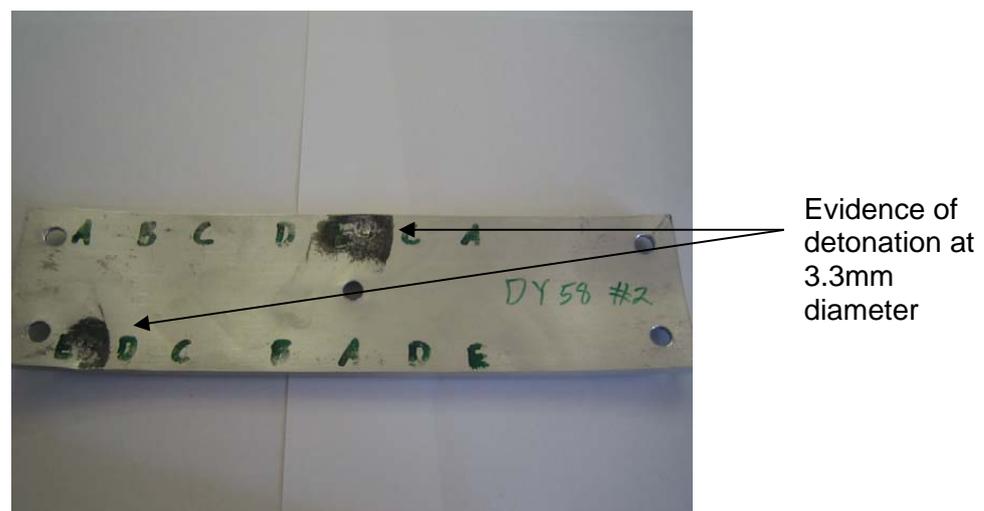**Table 6:** Results from Stage 2 Test

Figure 5: Witness Plate after Firing of **B** (A = 2.0mm hole diameter; B = 2.3mm; C = 2.6mm; D = 2.9mm; E = 3.3mm)

3.2 Initiation of IHE

The paste formulations were tested to determine whether they were capable of initiating an IHE (based on TATB). An experimental assembly was designed consisting of a base unit that contained the paste explosive and acts as a 'seat' for the acceptor (IHE) pellet and a cap to centre a piezoelectric probe on the acceptor (Figure 6). Three probes were used in the assemble to enable an estimate of detonation velocity in the paste.

The base unit was designed to hold a Reynolds RP-2 detonator in intimate contact with a 30mm column of paste explosive (15mm diameter), to ensure a stable detonation wave had been established in the paste before reaching the interface with

the acceptor charge (25mm diameter by 20mm length cylinder). The test configuration is shown in Figure 7.
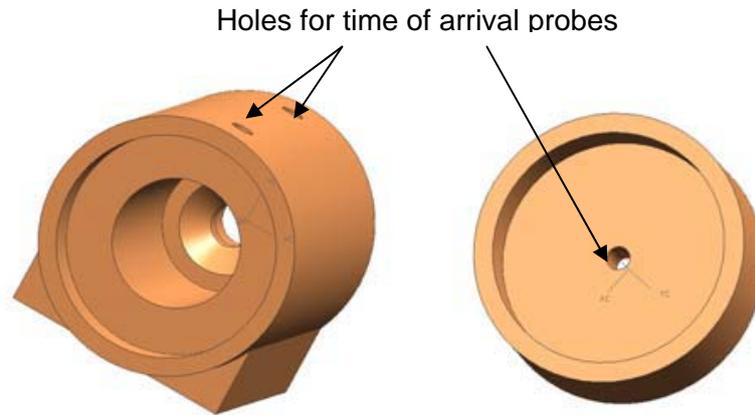
Holes for time of arrival probes

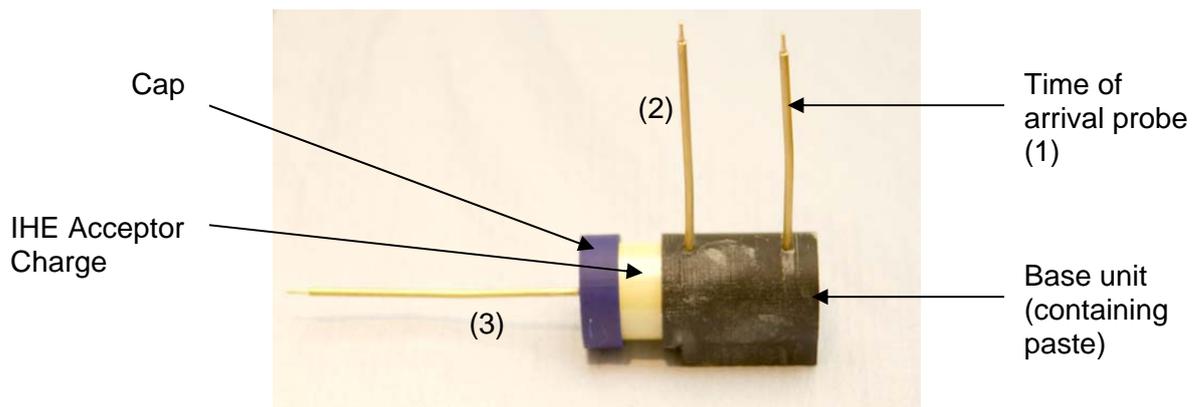**Figure 6:** Schematic of Base Unit (left) and Cap (right)

Figure 7: Assembly for IHE Initiation Test

A was not tested due to the sedimentation issues highlighted previously. Successful initiation of the IHE acceptor to full detonation was observed using both **B** and **C** as the donor material in the test geometry. This was indicated by triggering of the time of arrival probe (3) on the base of the acceptor pellet. The tests do not indicate whether the paste explosive promptly initiates the IHE or induces full detonation after a run distance. Time of arrival data for the tests are shown in Table 7.

	B	**C**
Probe (1)	1.992	2.020
Probe (2)	5.328	No data
Probe (3)	8.216	8.252

Table 7: Time of Arrival Data (μs)

Detonation velocity for the **B** firing was calculated for the full length of the acceptor charge under the assumption that the paste was promptly initiated by the detonator (simple calculations indicate that this was likely). This gave a figure of 7.6 mm/µs which is comparable to that obtained via the failure diameter test. Since the time measured from probe (1) to (3) is almost identical using **B** or **C** it is reasonable to suggest that the two materials have similar initiating properties towards IHE materials based on TATB.

4. Conclusions

This paper has detailed work on the development and evaluation of three new explosive paste formulations based on HMX with a liquid fluoropolymer. The three formulations, **A** (65% solids loading), **B** (70%) and **C** (75%) were prepared using an IKA 1 litre planetary mixer. Although each of the formulations was based on the same ingredients the variation in proportions yielded significantly different physical properties. Detonation properties have been confirmed based on donor/acceptor testing and a two stage critical diameter test. These tests yielded geometry specific detonation velocities.

The viscosity of **A** was found to be too low ('slurry' like) and unsuitable for applications where sedimentation could occur. Further work could be undertaken on a version of this material prepared with a rapid cure additive.

B had suitable viscosity to be filled into tracks. The viscosity was low enough to permit ease of filling and elimination of air bubbles whilst providing sufficient shape stability. The critical diameter was measured at 3.3mm when confined by PMMA (Perspex) and the formulation gave a sufficient detonation pressure to initiate an IHE.

The high viscosity and 'clumpy' nature of **C** presented difficulties in filling the test assemblies. The critical diameter was measured at between 2.7 and 3mm and the formulation gave a sufficient detonation pressure to initiate an IHE.

5. Future Work

Recent work has demonstrated the ability to increase the loading of HMX to 77 % to give a material with a good paste consistency (similar to that of **B**). This has been achieved by modifying the particle size distribution of the HMX.

Further work to investigate cure chemistry to give a dimensionally stable material is recommended. Curing a liquid fluoropolymer can be challenging due to lack of miscibility with commonly used binder materials and curing agents. This is currently being investigated.