Cook-off testing of pressed PBXs

Philip Cheese, Nathan White, Tom Reeves (UK MOD, Defence Equipment and Support), Tony Rowlands (Chemring UK) Chris Stennett (Defence Academy of the UK)

Introduction

The response of explosives to thermal stimuli is of paramount importance for assessing the safety of munitions, and for designing improved weapons to meet IM requirements. Munition thermal response is assessed and tested in fast heating and slow-heating scenarios, typified by liquid fuel fires (STANAG 4240) and slow cook-off at 3.3°C/hour heating rate. Together these tests have been assumed to induce the most violent reactions that can arise from thermal hazards. Experimental results reported in recent years have challenged this assumption.

To support UK and international projects to investigate the validity of the SCO heating rate in particular, Weapons OC, Chemring and Cranfield University have conducted a series of experiments on modern pressed, cast and melt cast explosives, across a range of heating rates.

Experimental programme

The test employed was the UK Qualification EMTAP 42 Tube Test - Electrically Heated. This is a highly confined steel cylinder containing ~350g of explosive, heated from ambient to explosion temperature at heating rates between 3.3 °C/hour and 1000 °C/min.

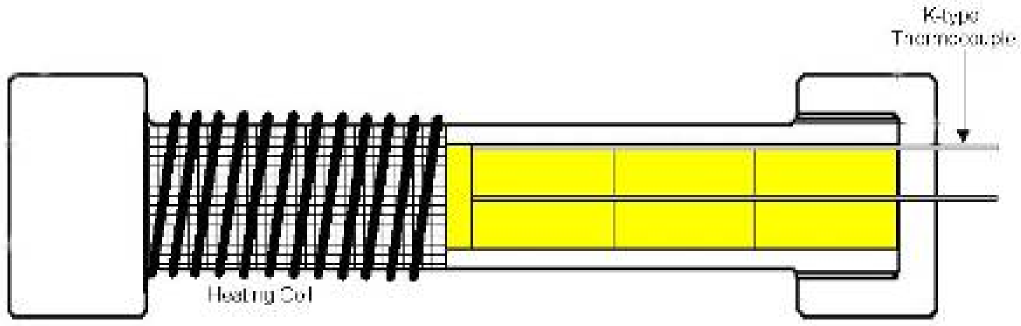

Figure 1 EMTAP 42 Tube Test - Electrically Heated

For energetic material qualification five tests are conducted at intermediate heating rates. The test reported here were done between 0.5 °C/min and 10 °C/min. Time to ignition and temperature of ignition are recorded, along with the degree of fragmentation of the tube. Typical test outputs are shown in Tables 1 and figures 2, 3 and 4, in this case for the pressed Polymer Bonded Explosive (PBX) LX-14.

Shot Number	Heating Rate (°C/min)	Temperature at Ignition	Time to Ignition (s)	Number of Body Fragments
1	5	258	2832	127
2	10	308	1704	140
3	2	243	6600	109
4	1	225	12360	>130
5	2	238	6570	>150

Table 1 EMTAP 42 Degree of reaction for LX-14

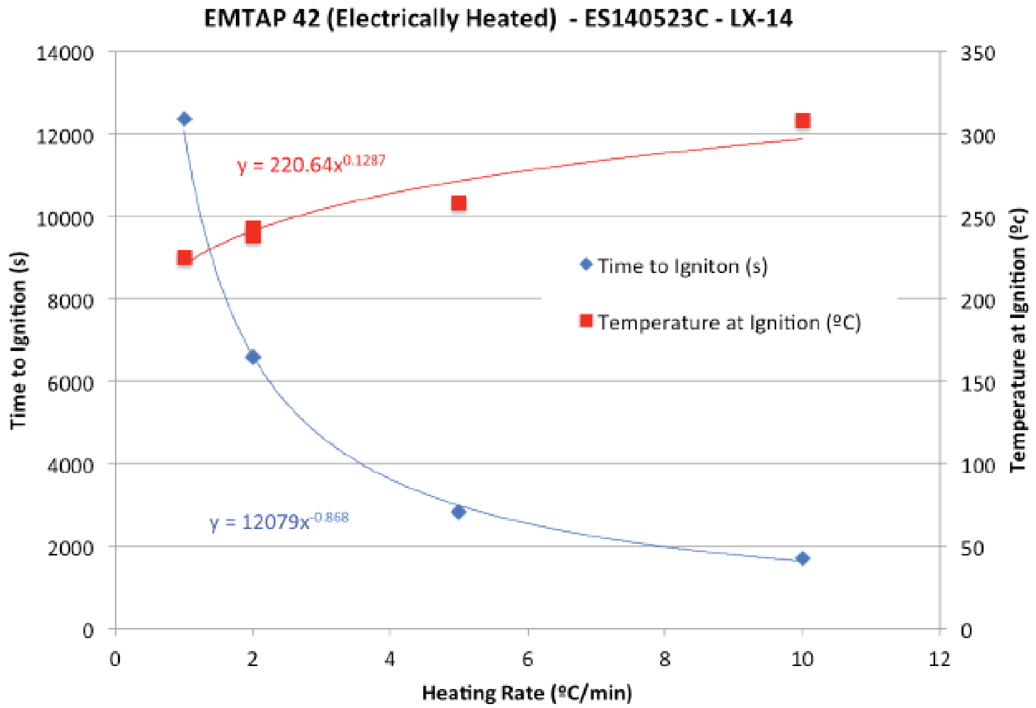

Figure 2 EMTAP 42 Time and temperature of ignition for LX-14

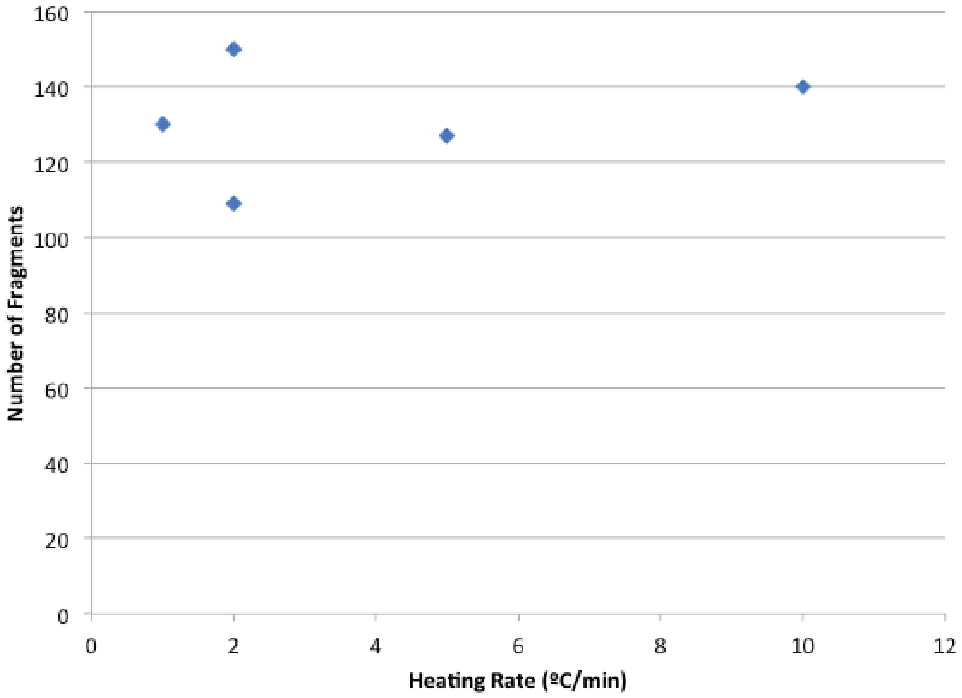

Figure 3 EMTAP 42 Fragmentation vs. heating rate for LX-14

Figure 4 EMTAP 42 typical fragmentation for LX-14

Explosives Tested

The explosives tested in this programme were all production standard materials supplied by Chemring, Most were pressed PBXs with Thermoplastic Elastomeric (TPE) based binder systems. Representative TNT based melt cast materials known to exhibit high explosiveness, and PBXs using Estane and Viton binders were also tested to provide a baseline for comparison.

TPE PBXs were chosen as the focus of the study as their high nitramine loading gives them very high performance coupled with mechanical properties that make them very suitable for use in shaped charge as and other metal driving warhead applications. However, they are known to exhibit higher explosiveness than cast cured HTPB PBX formulations like PBXN-109 and PBXN-110, which. The cast cured PBXs have very good hazard properties, and give very mild reactions to thermal threats, and to mechanical stimuli like bullet impact and fragment impact when tested below their shock to detonation transition threshold, but do not have the high performance and dimensional stability desirable for precision shaped charges.

It is possible that the higher explosiveness of the TPE PBXs could give rise to more violent reactions in system level tests than the cast cured PBXs, but at present there is no quantitative method that can predict the violence of response of explosives to non-shock hazards. This study sought to generate a body of evidence that would characterise the response of these explosives to thermal stimuli, that will be useful to munition designers, formulators, hazard testers and modellers. All of the formulations have been tested in the related tube tests EMTAP 35 – Internal Ignition and EMTAP 41 – Fast Heating. The results of these experiments will be reported in due course.

The nominal formulations of the explosives tested and the EMTAP 42 results obtained are summarised in Table 3. Results of particular importance for the slow cook-off question are discussed in the following section.

Explosive	Formulation	Total Fragments at Heatiing Rate (ºC/minute)				
		0.5	1	2	5	10
DPX1	92% RDX 2% Hytemp 6% DOA		3	3, 4	3	4
DPX1 Type III	92% Reduced Sensitivity RDX 2% Hytemp 6% DOA	4	5	5	4	4
DPX2 Type II	92% Improved HMX 2% Hytemp 6% DOA		5	2, 13	1	7,8
DPX3 Type I	96% HMX 1% Hytemp 3% DOA		18	33	26, 26	23
DPX3 Type II	96% Improved HMX1% Hytemp 3% DOA	56	41	25	29	11
DPX4	90% HMX 10% Viton		20	16	24, 25	29
DPX5	64.4% HMX 1.4% Hytemp 4.2% DO 30% Aluminium		5	7	3, 4	10
DPX7 Type I	86% HMX 1% Hytemp 3% DOA 10% Aluminium Class6			198, 202	122, 351	159
DPX7 Type II	86% HMX 1% Hytemp 3% DOA 10% Aluminium Class7		185	250	202, 222	144
DPX8 Type I	76% HMX 1% Hytemp 3% DOA 20% Aluminium Class6		9	11	6, 7	14
DPX8 Type II	76% HMX 1% Hytemp 3% DOA 20% Aluminium Class7		17	16	19, 23	48
DPX10 Type 1	86.5% RDX 5.95% DOS 3.23% Poly 190 3.23% Oppanol B 15N 1% DMNB		6		1	1
DPX10 Type II	87.5% RDX 10.4% PIB's 2.1% DOS 1.25% DMNB (added)		4	4	6, 8	8
DPX11	77% HMX 2% Hytemp 6% DOS 15% Al Class 6		4	4, 6	4	4
DPX12	64.4% RDX 1.4 % Hytemp 4.2% DOS 30% Al Class 7		5	4, 180	197	4
LX-14	95.5% HMX 4.5% Estane		163	123, 182	129	142
PBXN-10	92% RDX Type II 2% Hytemp 6% DOA		7	4,5	3	8
Octol 70/30	70% HMX 30% TNT		100	100	100	9, 10
HBX-3	RDX/TNT/Al/+ 31/29/35/5		2	7	8	1, 4
Comp B	64% RDX 36% TNT		162	144	78	80, 152

Table 2 Nominal formulations and EMTAP 42 Fragmentation

Analysis

The TNT based explosives Comp B and Octol 70/30 showed high levels of fragmentation, indicating detonation or violent deflagration at all most heating rates. HBX-3 with has a lower nitramine content than the other two, and gave relatively mild reactions at all heating rates. These reactions are typical for explosives of this type, and frequently give rise to violent reactions in full scale testing of munitions they are used in.

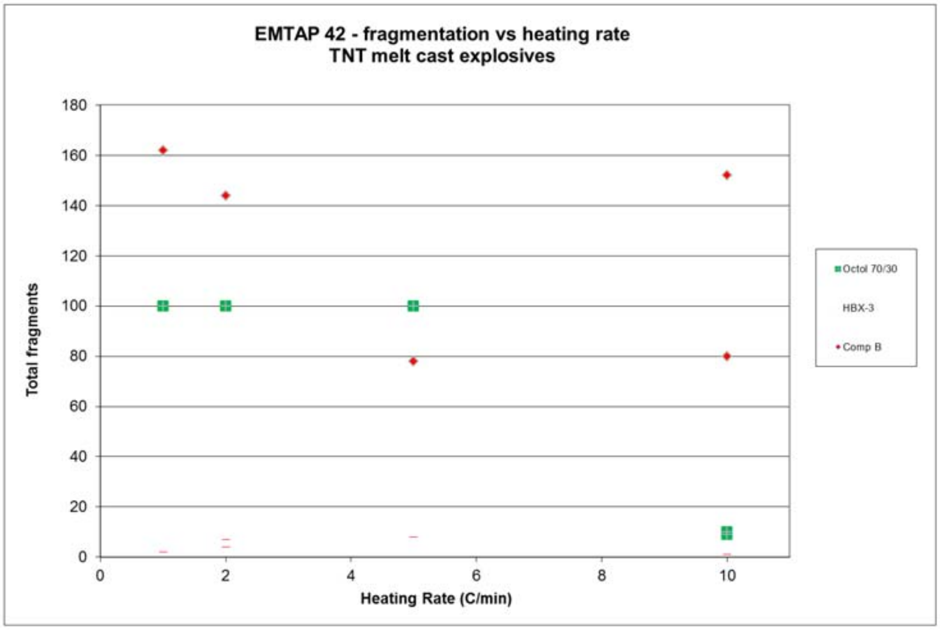

Figure 5 Fragmentation vs. heating rate for TNT based explosives

The results for TPX PBXs containing HMX, both with and without Al are presented in Figure 6. This summary chart shows that TPE PBXs can exhibit both low and high explosiveness in this test, at heating rates between 0.5 °C/min and 10 °C/min

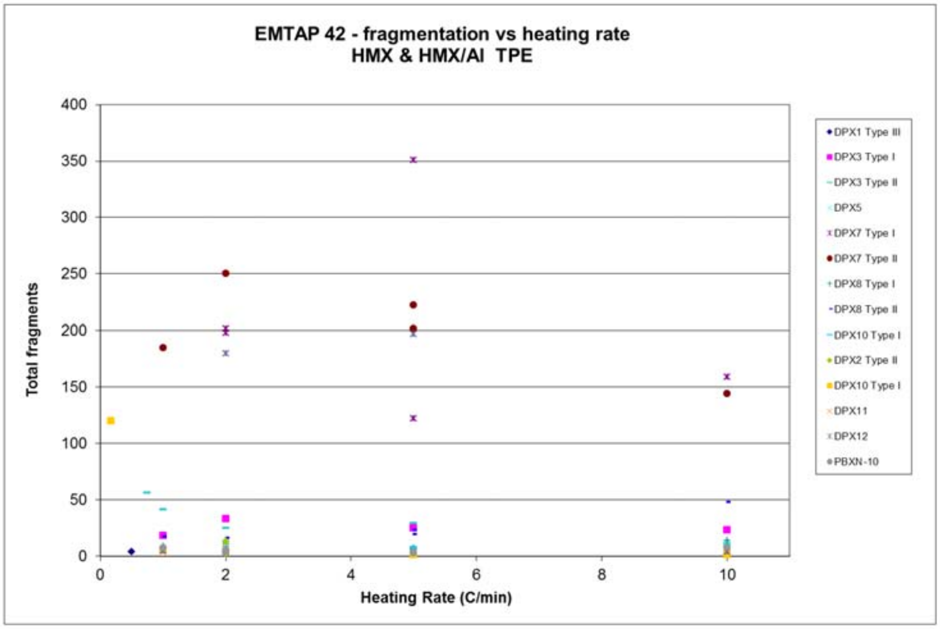

Figure 6 Fragmentation vs. heating rate for HMX based TPE PBXs

Figure 7 shows that explosives containing a very high HMX loading show a general decrease in explosiveness as heating rate increases over the range studied. DPX3 Type I and Type II have lower explosiveness than Octol 70/30 and Comp B. Results for the similar explosive PBXW-11 show the same downward trend in explosiveness towards higher heating rates, but is more violent than the DPX formulations at all heating rates.

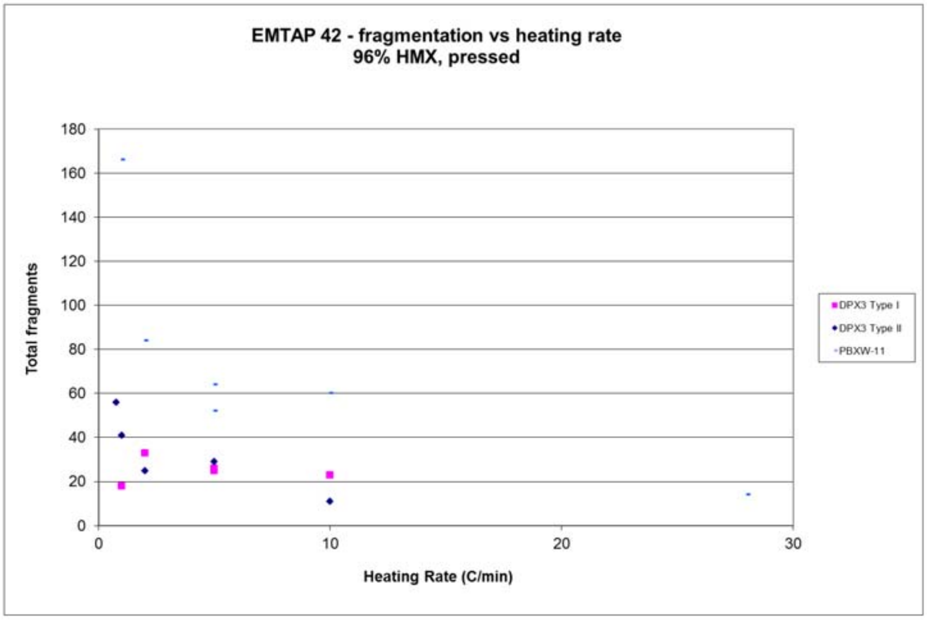

Figure 7 Fragmentation vs. heating rate for 96% HMX TPE PBXs

The two explosives with 64.4% HMX, 30% Al and 5.6% TPE binder, show very different behaviour. DPX5 gave low fragmentation at all heating rates tested, whereas DPX-12 gave 198 fragments at 5 °C/min, 180 and 4 fragments at 2 °C/min, and 4-5 fragmenta at other rates.

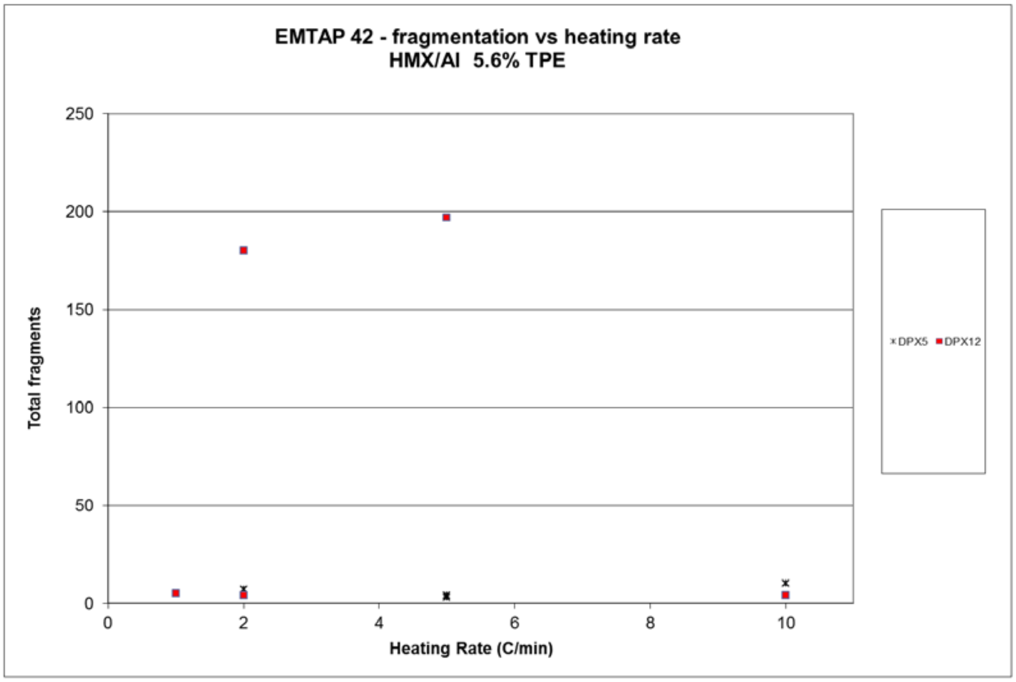

Figure 8 Fragmentation vs. heating rate for 5.6% binder HMX/Al PBXs

The results for HMX PBXs with 4% TPE binder and 0, 10 and 20% Al are presented in Figure 9.

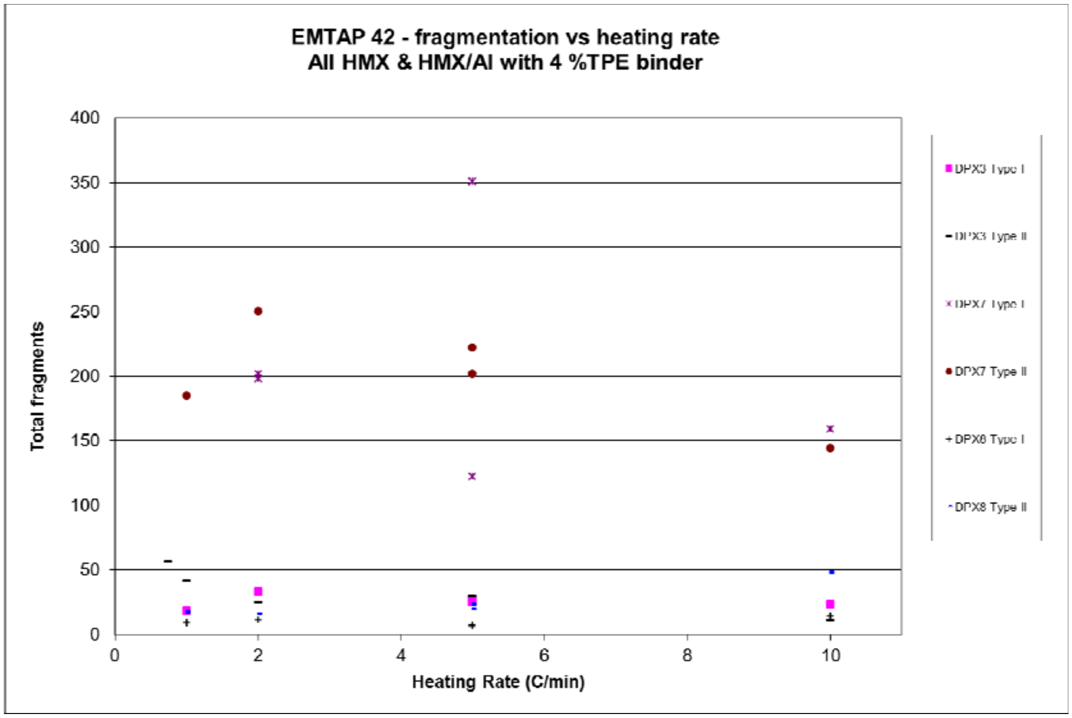

Figure 9 Fragmentation vs. heating rate for 4% TPE binder HMX and HMX/Al

It is apparent that DPX7 Type I and II gave very violent reactions at all heating rates tested. DPX3 Type I and II contain no Al and gave much less violent reactions, as did DPX8 Type I and II which contain 20% Al of the same class as DPX 7 Type I and II (Class 6 and 7 respectively). Typical fragmentation patterns are shown in Figure 10.

Conclusions

1. TNT based melt cast explosives including Comp B and Octol 70/30 gave violent reactions at all heating rates tested;

2. The HMX/Estane PBX, LX-14, gave violent reactions at all heating rates tested;

3. Pressed PBXs with Thermoplastic-elastomeric (TPE) binder, with solids loading up to 96% mostly give much less violent reactions than LX-14 and TNT based melt cast explosives;

4. A variation of reaction violence with heating rate between 1 & 10 ºC/min was observed for an RDX/Al/TPE explosive;

    - Violent reactions occurred at 2 ºc/min and 5 ºC/min
    - Mild reactions occurred at 1, 2 and 10 ºc/min

5. A correlation between **formulation** and **violence** was observed across this range of heating rates for explosives containing HMX and Al with 4% TPE binder:

    - Mild reactions were observed for 96/4 HMX/TPE and 76/20/4 HMX/Al/TPE at all rates;
    - Violent reactions were observed for 86/10/4 HMX/Al/TPE.

Summary

That Comp B, Octol and LX-14 show poor hazard properties in slow cook-off testing is no surprise; they provide the reference that all IM candidate explosives must exceed.

The results presented here support the belief that TPE binders can contribute to, but do not guarantee, good hazard properties in slow cook-off. They do not have the intrinsic low explosiveness of the cast cured PBXs like PBXN-109 and PBXN-110, so care must be taken when designing warheads around them if good IM results are to be achieved.

However, it is clear that variations in the violence of cook-off events with heating rate or formulation are not predictable. For example, the results for DPX3, DPX7 and DPX8 show that relatively small changes in formulation can produce very large changes in violence of reaction, and there is no reason to suppose that there are clean, simple patterns by which the expected response of any explosive formulation could be classified.

Finally, these results demonstrate clearly that the extreme heating rates typified by the 3.3 ºC/hour slow cook-off rate and the fuel-fire environment do not necessarily produce the most violent possible response for any explosive in any weapon, and provide a strong motivation for revisiting the assumptions that underpin their use as international standards.

sfds