Cook-off testing of pressed PBXs

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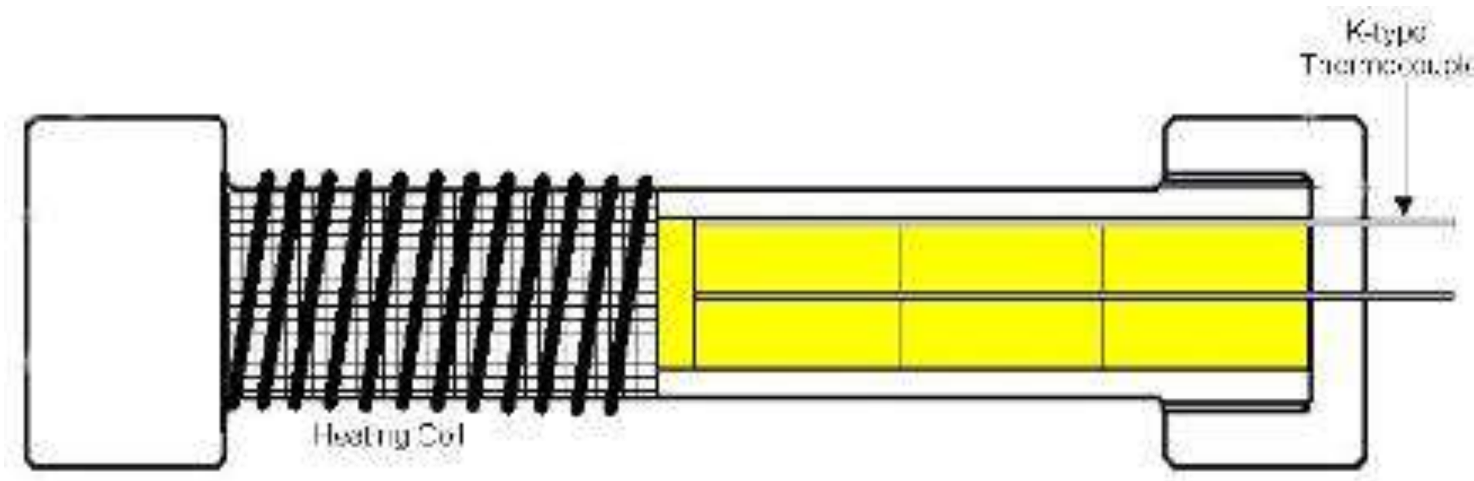
Weapons Operating Centre

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 ºC/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 Defence Academy have conducted a series of experiments on modern pressed, cast and melt cast explosives, across a range of heating rates.

EMTAP 42 Tube Test – Electrically Heated

- This paper reports the results of slow cook-off tests using the UK standard test used for material qualification of explosives

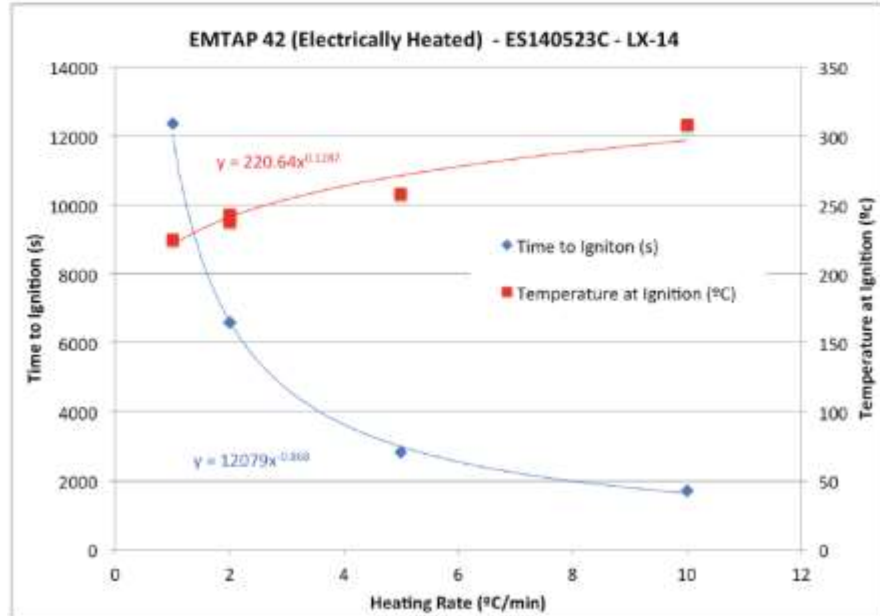


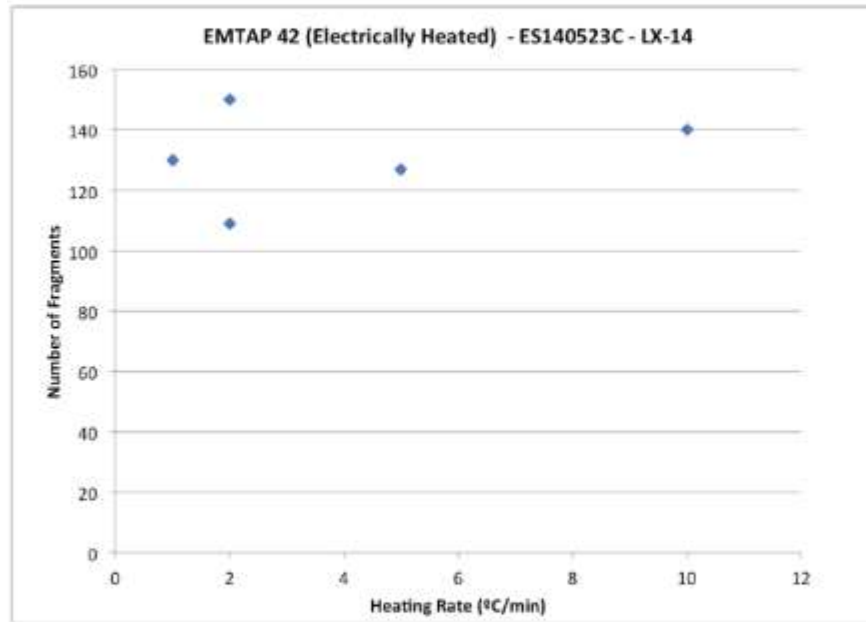
- Highly confined steel cylinder containing ~350g of explosive
- Internal diameter 31.4 mm, 6.1mm wall thickness
- Heated from ambient to explosion temperature at heating rates between 3.3 & 1000 ºC/min.
- Test reported here use rates between 0.5 ºC/min and 10 ºC/min

Results for LX-14

TEST RESULTS: Composition LX-14						
Firing ID	HE Density (g/cc)	Recovered Fragments			%HE Recovered	Degree of reaction
		Total	Body	%wt		
ES140523C-708	1.76±0.01	129	127	98	0	4
ES140523C-705	1.76±0.01	142	140	98	17	4
ES140523C-706	1.76±0.01	123	109	93	0	4
ES140523C-707	1.77±0.01	>153	>130	95	0	4
ES140523C-703	1.77±0.01	>182	>150	98	0	4

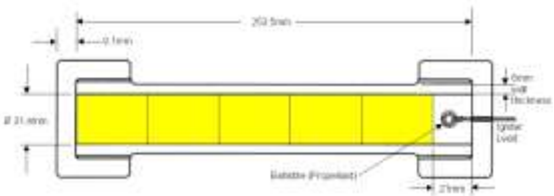
Shot Number	Heating Rate (°C/min)	Temperature at Ignition	Time to Ignition (s)	Number of Body Fragments
1	5	258	2832	127
2	10	308	1704	140
3	2	243	6600	109
4	1	225	12360	>130
5	2	238	6570	>150

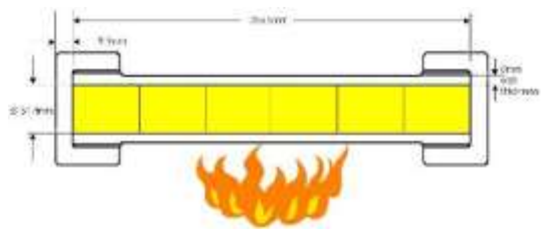


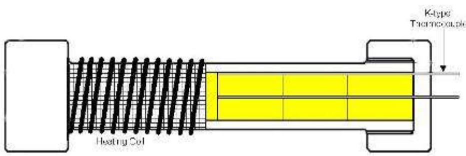


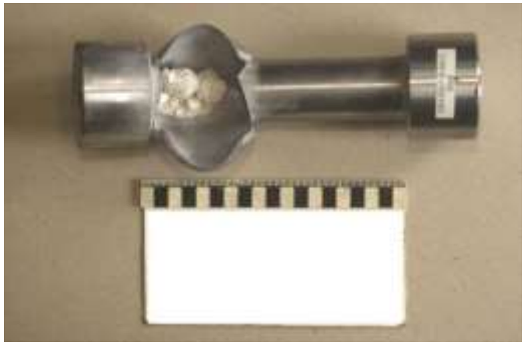
Other EMTAP Tube Tests

- 35 – Internal Ignition and 41 – Fast Heating (fuel fire)
- Materials that have passed the tube tests have not caused issues in IM tests
- Materials that have detonated in the tube tests have detonated in IM tests









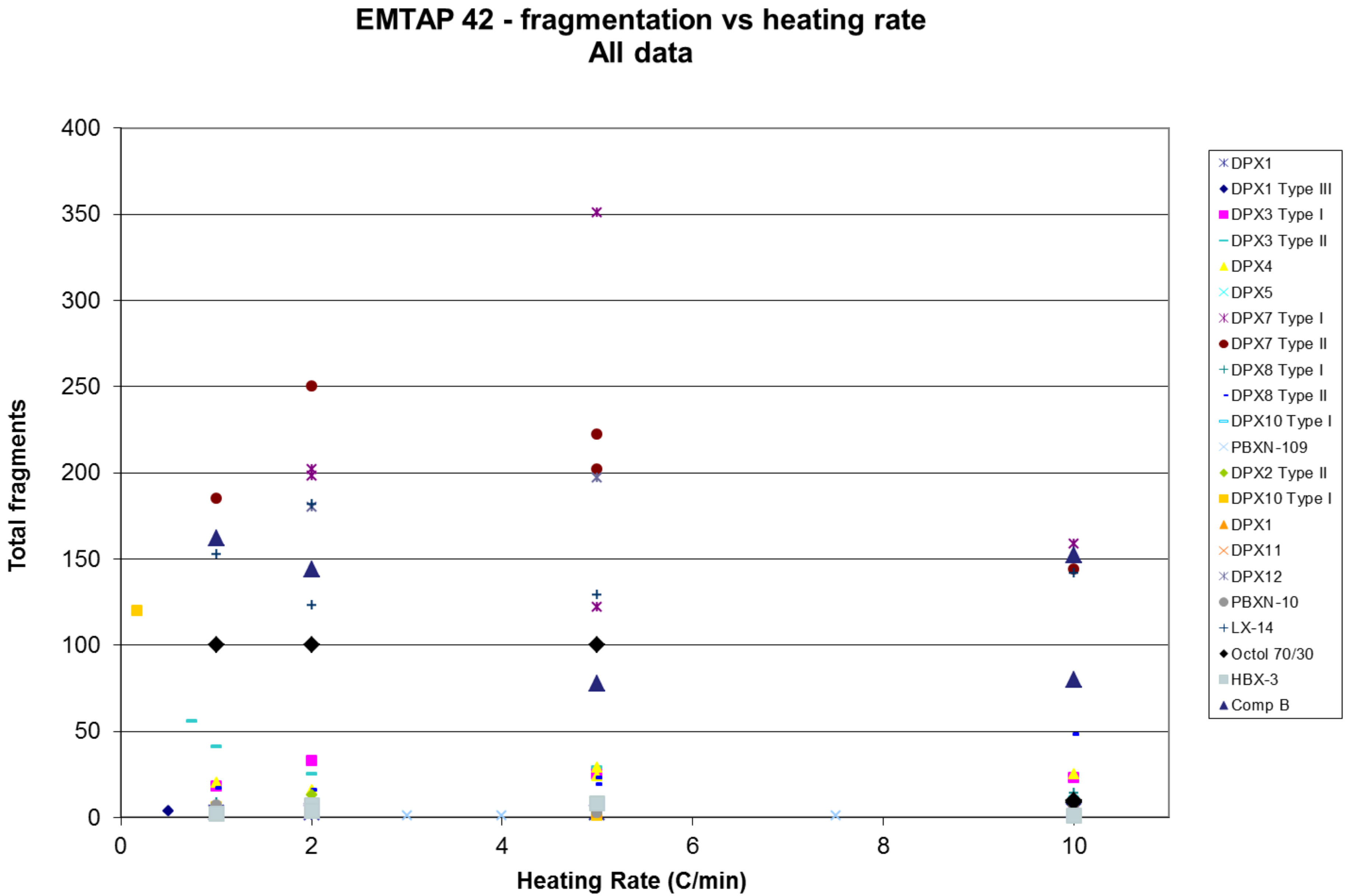
- Results for these tests will be reported in due course

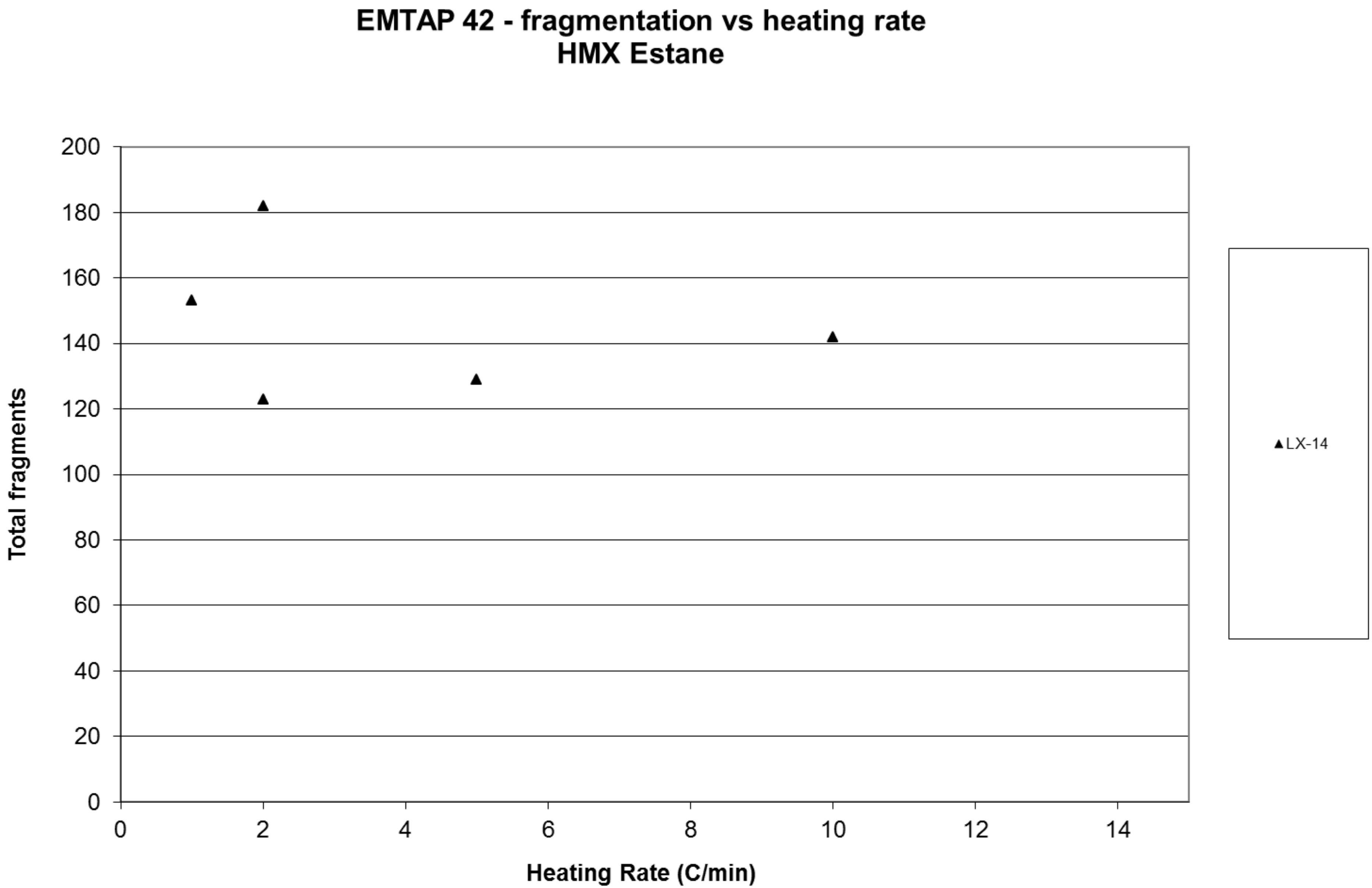
Explosives tested

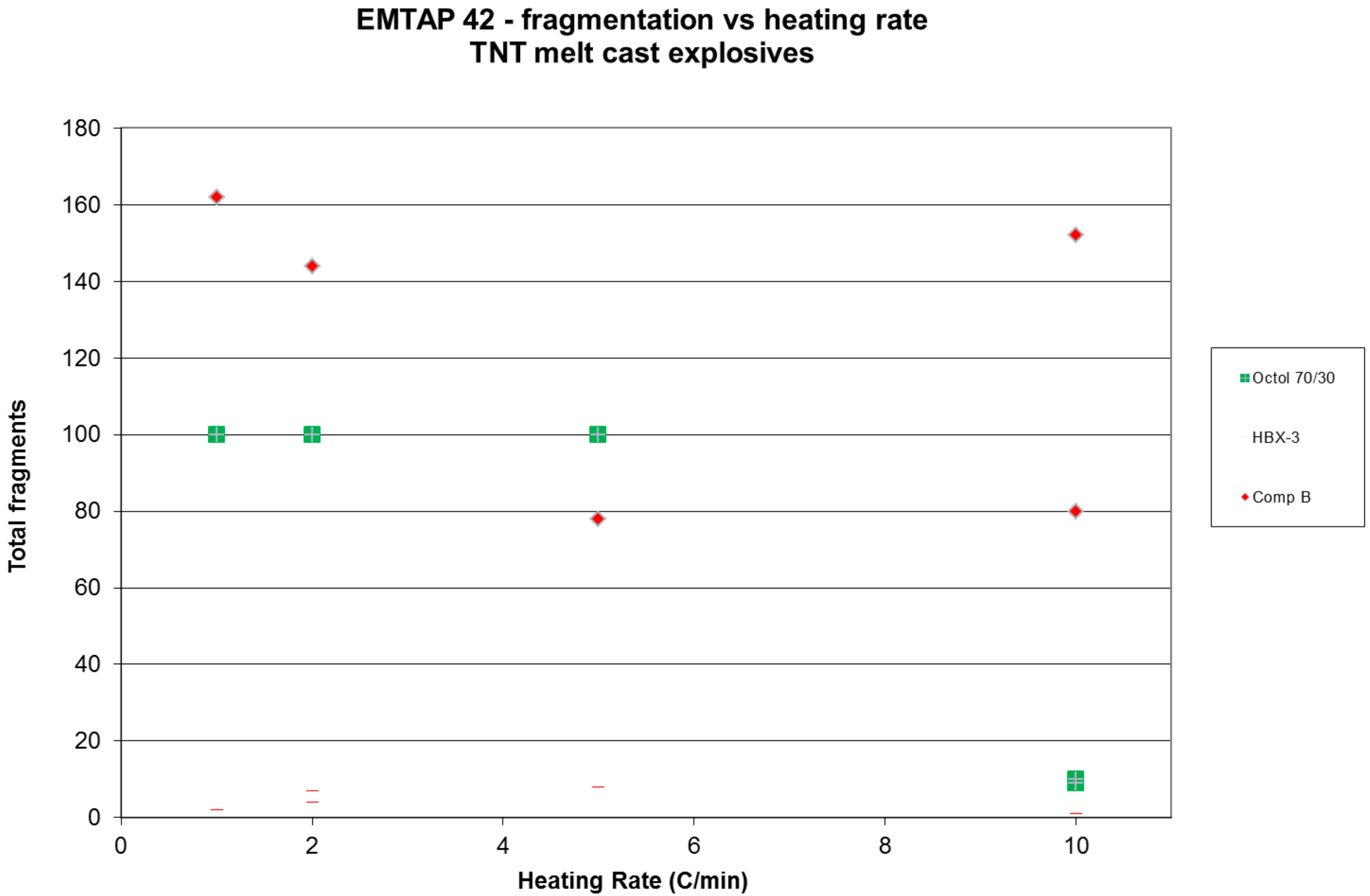
DPX1	**92% RDX 2% Hytemp 6% DOA**
DPX1 Type III	**92% Reduced Sensitivity RDX 2% Hytemp 6% DOA**
DPX2 Type I	**92% HMX 2% Hytemp C966% DOA**
DPX2 Type II	**92% Improved HMX 2% Hytemp 6% DOA**
DPX3 Type I	**96% HMX 1% Hytemp 3% DOA**
DPX3 Type II	**96% Improved HMX1% Hytemp 3% DOA**
DPX4	90% HMX 10% Viton
DPX5	**64.4% HMX 1.4% Hytemp 4.2% DO 30% Aluminium**
DPX7 Type I	**86% HMX 1% Hytemp 3% DOA 10% Aluminium Class6**
DPX7 Type II	**86% HMX 1% Hytemp 3% DOA 10% Aluminium Class7**
DPX8 Type I	**76% HMX 1% Hytemp 3% DOA 20% Aluminium Class6**
DPX8 Type II	**76% HMX 1% Hytemp 3% DOA 20% Aluminium Class7**
DPX10 Type 1	86.5% RDX 5.95% DOS 3.23% Poly 190 3.23% Oppanol B 15N 1% DMNB
DPX10 Type II	87.5% RDX 10.4% PIB's 2.1% DOS 1.25% DMNB (added)
DPX11	**77% HMX 2% Hytemp 6% DOS 15% Al Class 6**
DPX12	**64.4% RDX 1.4 % Hytemp 4.2% DOS 30% Al Class 7**
LX-14	95.5% HMX 4.5% Estane
PBXN-10	**92% RDX Type II 2% Hytemp 6% DOA**
Octol 70/30	70% HMX 30% TNT
HBX-3	RDX/TNT/Al/+ 31/29/35/5
Comp B	64% RDX 36% TNT

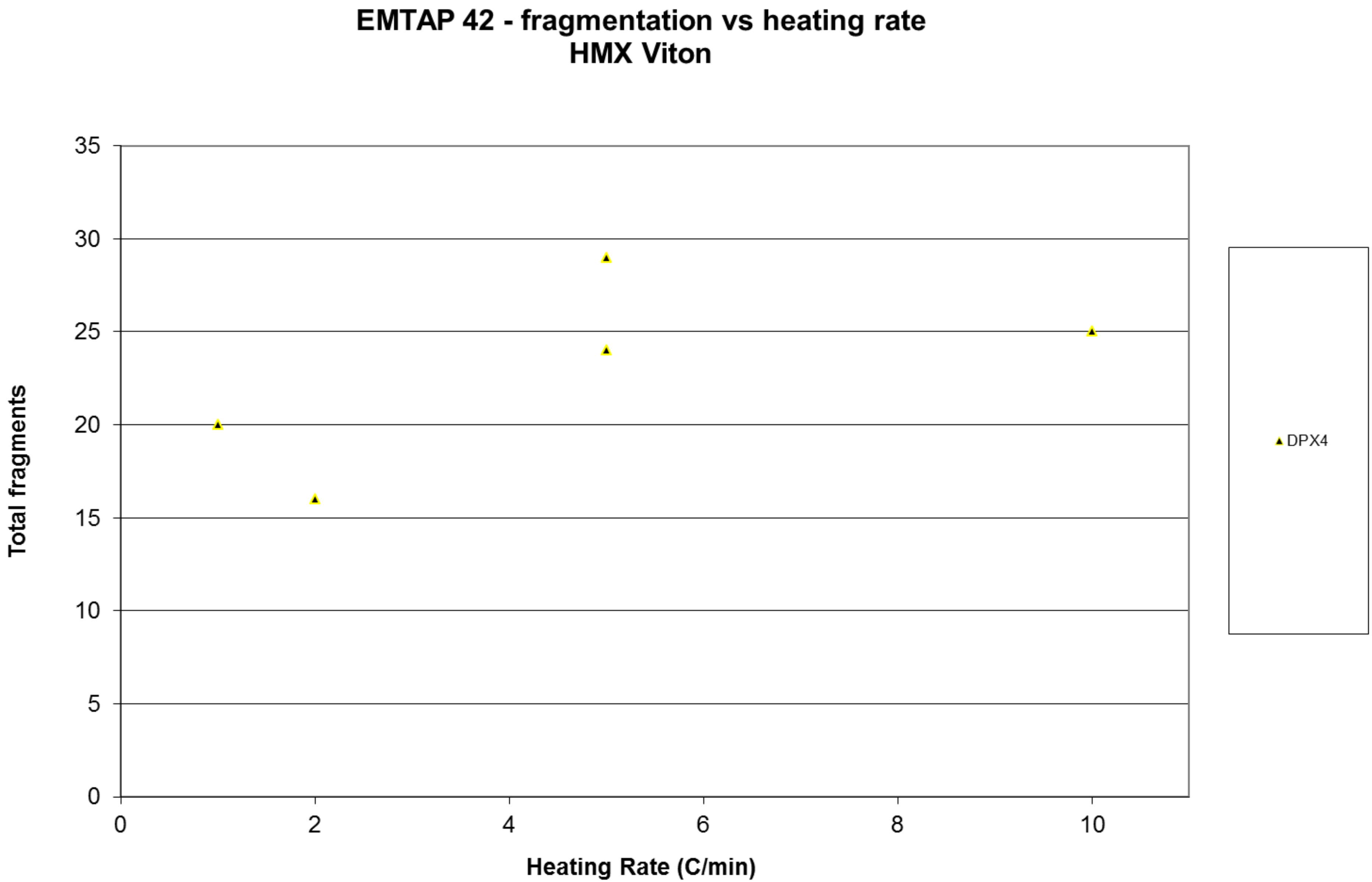
Results

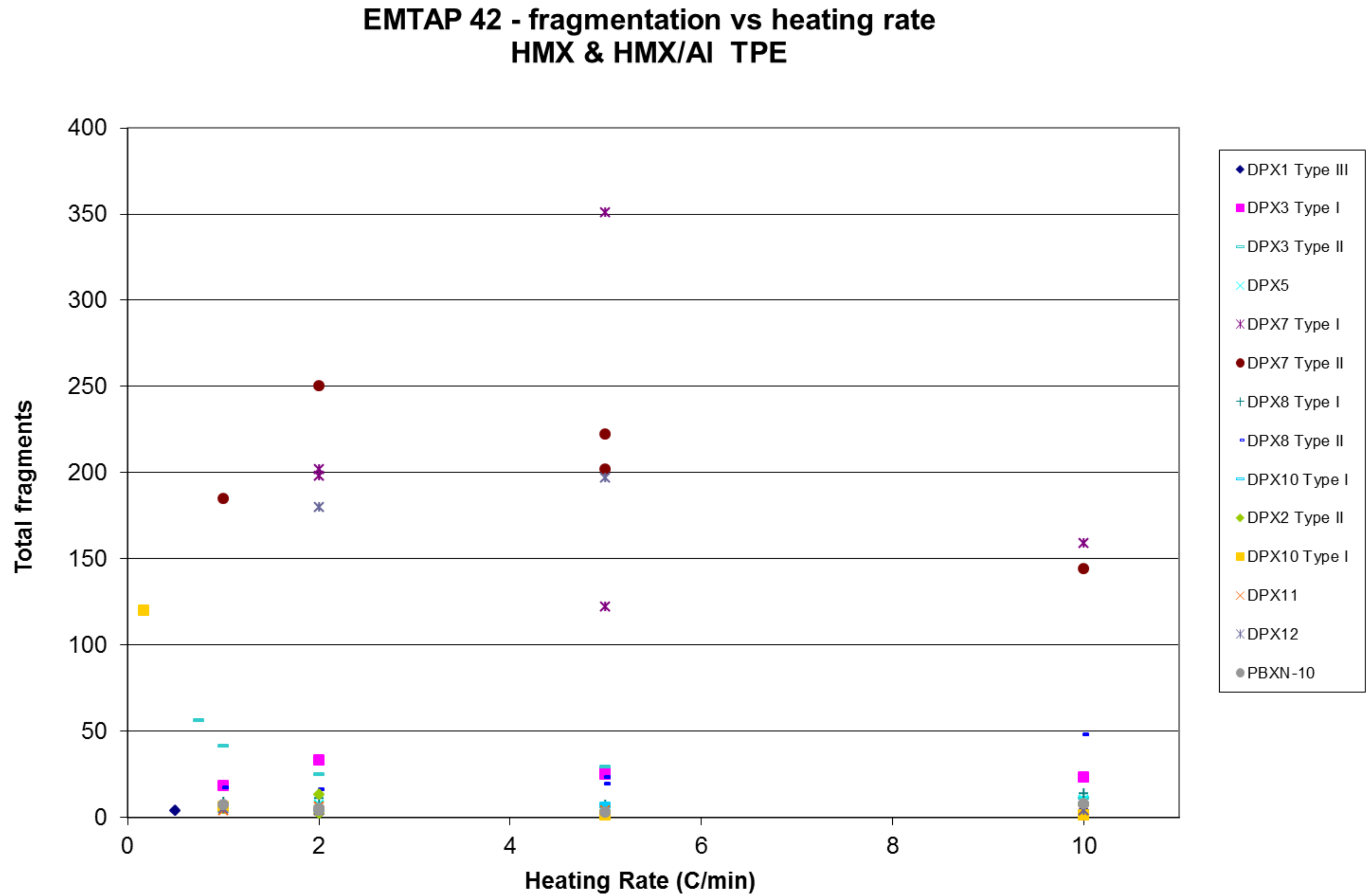
Explosive	Total Fragments at Heatiing Rate (ºC/minute)				
	0.5	1	2	5	10
DPX1		3	3, 4	3	4
DPX1 Type III	4	5	5	4	4
DPX2 Type II		5	2, 13	1	7,8
DPX3 Type I		18	33	26, 26	23
DPX3 Type II	56	41	25	29	11
DPX4		20	16	24, 25	29
DPX5		5	7	3, 4	10
DPX7 Type I			198, 202	122, 351	159
DPX7 Type II		185	250	202, 222	144
DPX8 Type I		9	11	6, 7	14
DPX8 Type II		17	16	19, 23	48
DPX10 Type 1		6		1	1
DPX10 Type II		4	4	6, 8	8
DPX11		4	4, 6	4	4
DPX12		5	4, 180	197	4
LX-14		163	123, 182	129	142
PBXN-10		7	4,5	3	8
Octol 70/30		100	100	100	9, 10
HBX-3		2	7	8	1, 4
Comp B		162	144	78	80, 152


EMTAP 42 - fragmentation vs heating rate
All data
Total fragments
Heating Rate (C/min)
0
50
100
150
200
250
300
350
400
0
2
4
6
8
10
DPX1
DPX1 Type III
DPX3 Type I
DPX3 Type II
DPX4
DPX5
DPX7 Type I
DPX7 Type II
DPX8 Type I
DPX8 Type II
DPX10 Type I
PBXN-109
DPX2 Type II
DPX10 Type I
DPX1
DPX11
DPX12
PBXN-10
LX-14
Octol 70/30
HBX-3
Comp B

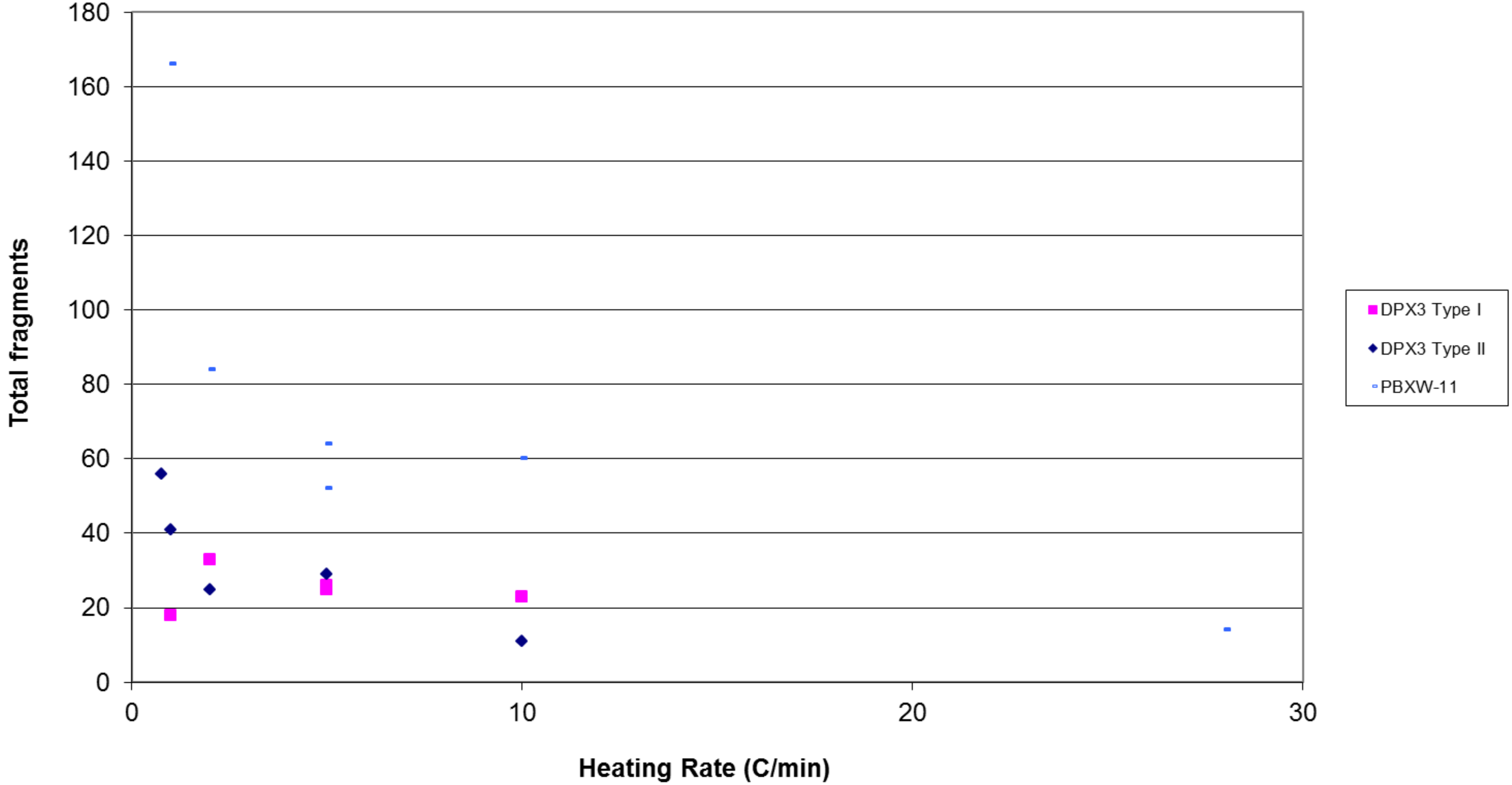

EMTAP 42 - fragmentation vs heating rate
HMX Estane
Total fragments
200
180
160
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
Heating Rate (C/min)
LX-14

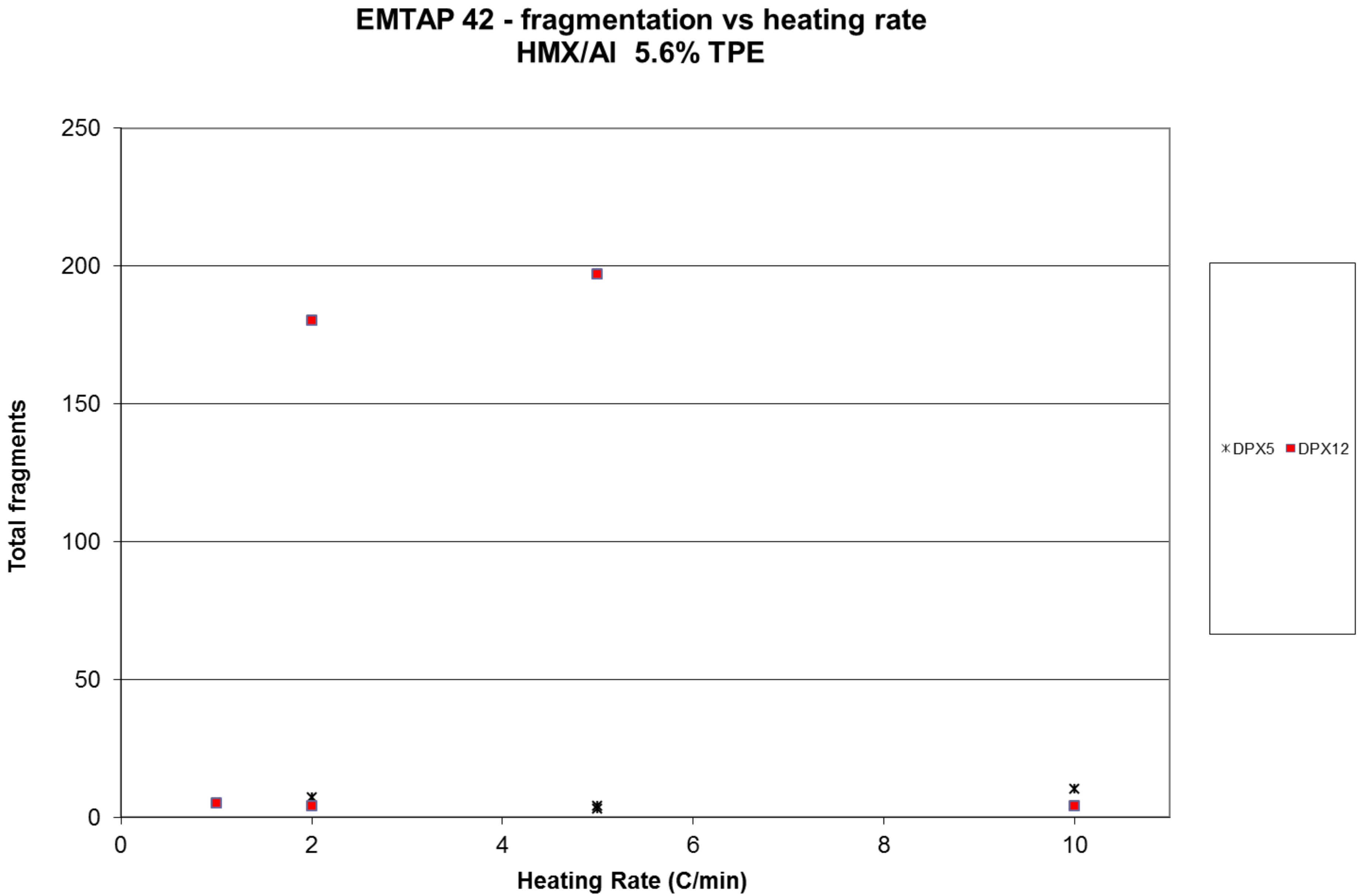

EMTAP 42 - fragmentation vs heating rate
TNT melt cast explosives
Total fragments
180
160
140
120
100
80
60
40
20
0
0
2
4
6
8
10
Heating Rate (C/min)
Octol 70/30
HBX-3
Comp B


EMTAP 42 - fragmentation vs heating rate
HMX Viton
Total fragments
35
30
25
20
15
10
5
0
0
2
4
6
8
10
Heating Rate (C/min)
DPX4

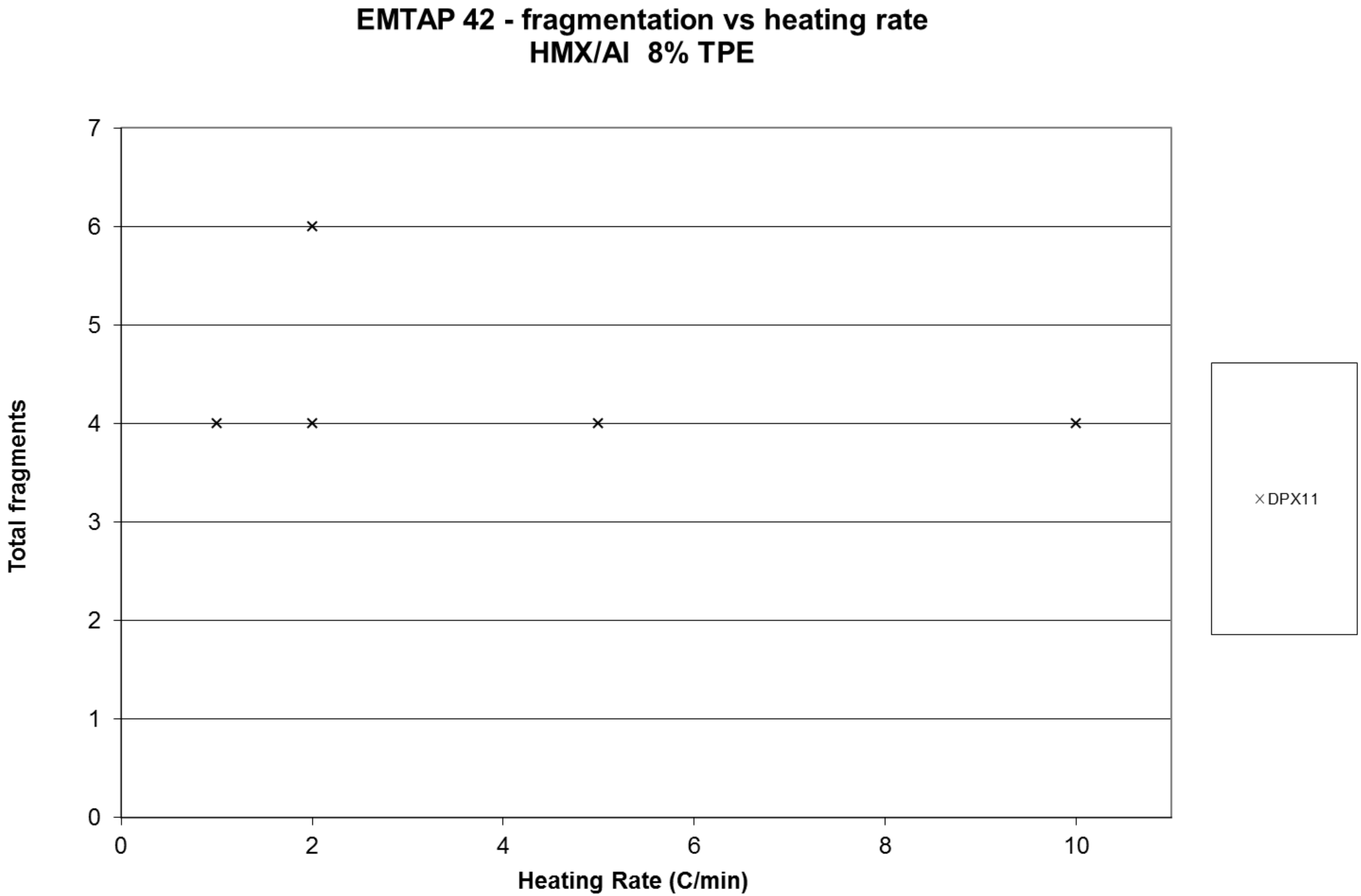

EMTAP 42 - fragmentation vs heating rate
HMX & HMX/Al TPE
Total fragments
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
Heating Rate (C/min)
DPX1 Type III
DPX3 Type I
DPX3 Type II
DPX5
DPX7 Type I
DPX7 Type II
DPX8 Type I
DPX8 Type II
DPX10 Type I
DPX2 Type II
DPX10 Type I
DPX11
DPX12
PBXN-10

EMTAP 42 - fragmentation vs heating rate
96% HMX, pressed

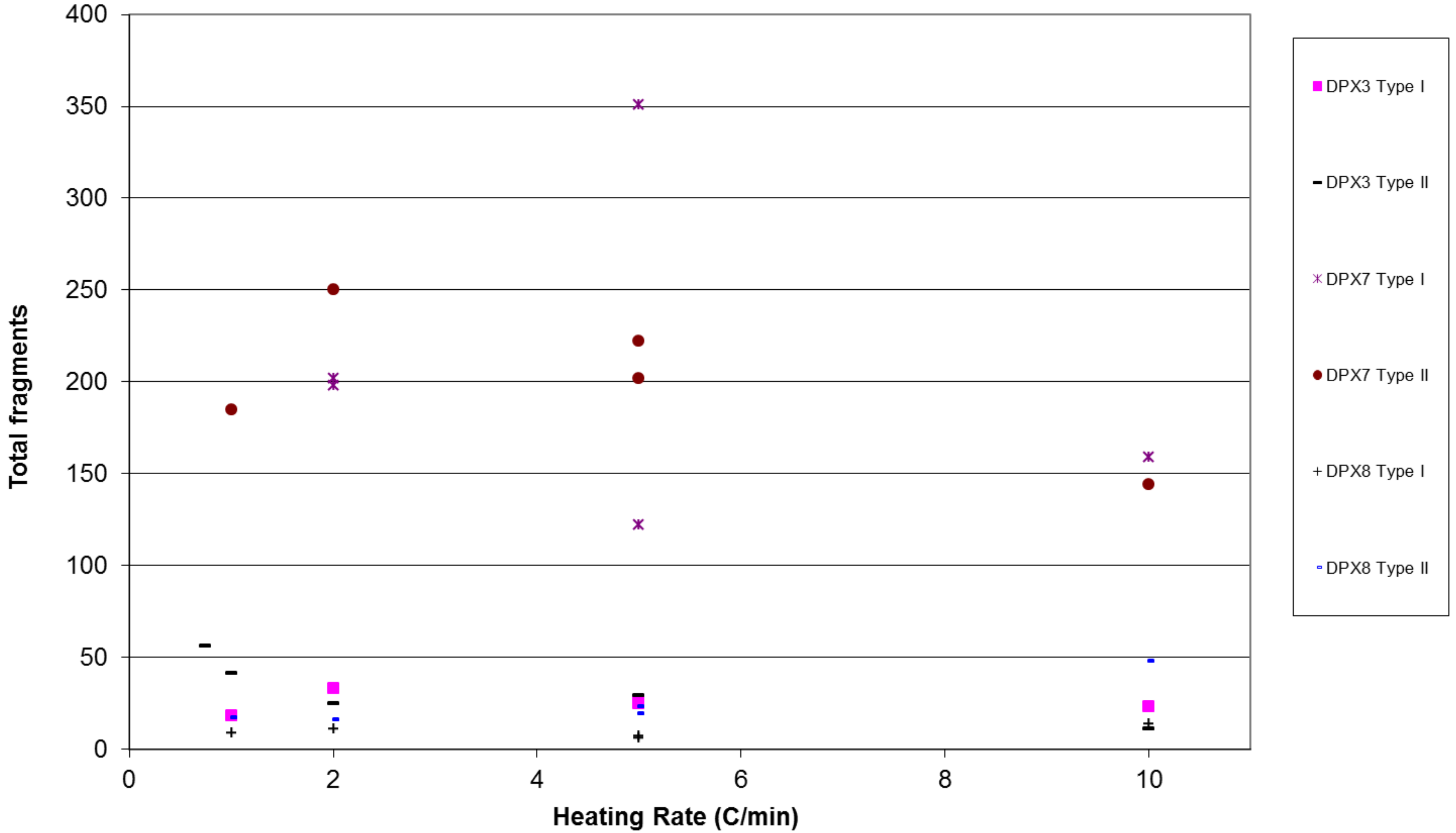


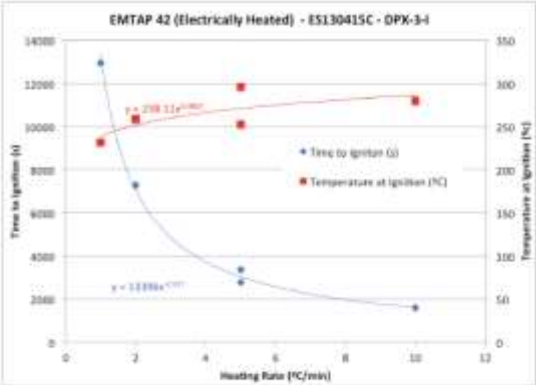


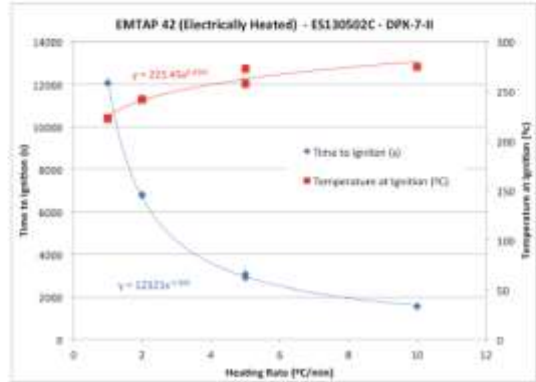
EMTAP 42 - fragmentation vs heating rate
HMX/Al 5.6% TPE
250
200
150
100
50
0
Total fragments
0
2
4
6
8
10
Heating Rate (C/min)
DPX5
DPX12

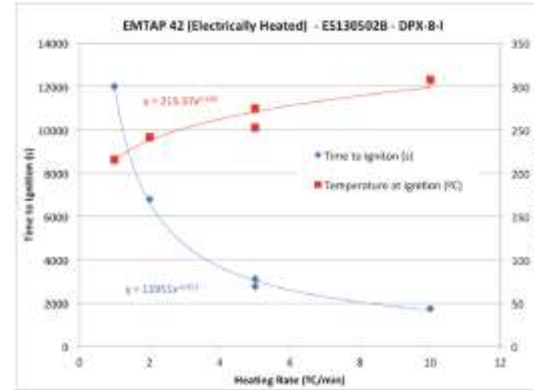

EMTAP 42 - fragmentation vs heating rate
HMX/Al 8% TPE
Total fragments
0
1
2
3
4
5
6
7
0
2
4
6
8
10
Heating Rate (C/min)
DPX11

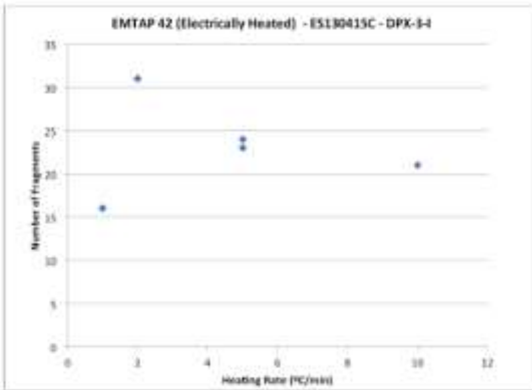
EMTAP 42 - fragmentation vs heating rate
All HMX & HMX/Al with 4 %TPE binder

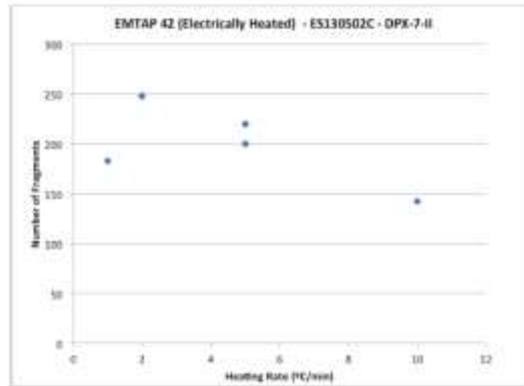


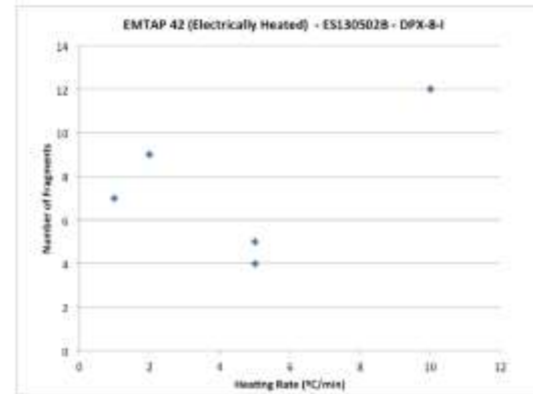












0% Al

10% Al

20% Al

Conclusions 1/2

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

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

- 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.

Conclusions 2/2

- A variation of reaction violence with heating rate between 1 & 10 ºC/min was observed for an RDX/Al/TPE explosive
  - The violent reactions occurred at 2 ºc/min and 5 ºC/min
  - Mild reactions occurred at 1, 2 and 10 ºc/min

- 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

- Legacy explosives Comp B, Octol and LX-14 have poor hazard properties in slow cook-off testing.
  - No surprise
- TPE binders can contribute to, but do not guarantee, good hazard properties in slow cook-off.
  - Compare with HTPB cast-cured PBXs
- Variations in violence of cook-off events with heating rate are not predictable.
- **The 3.3 ºC/hour heating rate and fuel-fire environment do not necessarily produce the most violent possible response for any explosive in any weapon.**

Acknowledgements

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