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HE Formulation for and Full-scale Characterisation of an IM Missile Fragmentation Warhead

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Outline

- Background
- Introduction
- High Explosive formulation
- Small-scale characterisation
- Full-scale performance evaluation
- Full-scale IM demonstration

Background

- Denel started experimenting with plasticised Hytemp-based formulations in 2001.
- Formulation successfully tested in a high-setback configuration.
- Results reported in papers presented at Parari 2003 & 2005.
- Work continued to formulate a High Explosive for a fragmentation warhead to render missile systems IM compliant

Introduction

- Superior IM properties of PBX's based on Hytemp and DOA plasticisers are well known.
- Cast PBX investigations at Denel proved that:
  - Coating RDX or HMX with DOA desensitises explosive effectively
  - Explosive content and crystal size distribution are key factors of sensitivity
- Initiation results from interaction between shockwaves and non-homogeneity in pressed compositions (so-called hot spots formed by void collapse along with impact and friction between particles).
- Explosive could therefore also be desensitised by minimising voids.
- Suitable thermoplastic elastomer (TPE) to introduce IM properties to pressed PBX required.
- Hytemp series of TPE's well known as pressed PBX binders and was an obvious choice for investigation.

HE Formulation

- Reference: RXCX-1
  - RDX-based Pressed PBX
  - Cariflex as inert TPE binder
  - Poor IM properties
- Preferred characteristics of an IM alternative
  - RDX-based
  - No energetic binder
  - Pressed PBX
  - Good machineability
- Formulations evaluated
  - Plasticised binder system based on Hytemp 4454
  - RDX-based (RXHR-6)
  - HMX-based (HXHR-1)

HE Formulation Properties

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Performance of IM Formulations Compared to Baseline

Property	Formulation		
	RXCX-1	RXHR-6	HXHR-1
Density (g/cc)	1.717	1.669	1.765
VOD_{exp} (m/s)	8440	8247	8586
P_{BKW} (kbar)	297	273	299
Gurney Energy $_{BKW}$ (m/s)	2765	2709	2756

- Theoretical effectiveness study concluded that RXHR-6 would meet the system performance requirement.

Small-scale Testing

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Sensitivity comparison of HE formulations (Gap Test)

Formulation	Gap for 50% transfer probability
RXCX-1	50 mm
PBXW-17	38 mm
RXHR-6	28 mm
HXHR-1	35 mm

- Extensive vulnerability testing in a standard configuration used for the establishment of technology supported the above Gap Test evaluations.

Full-scale Performance Evaluation

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Arena testing of RXHR-6

- Performance specification achieved
  - Fragment distribution
  - Penetration

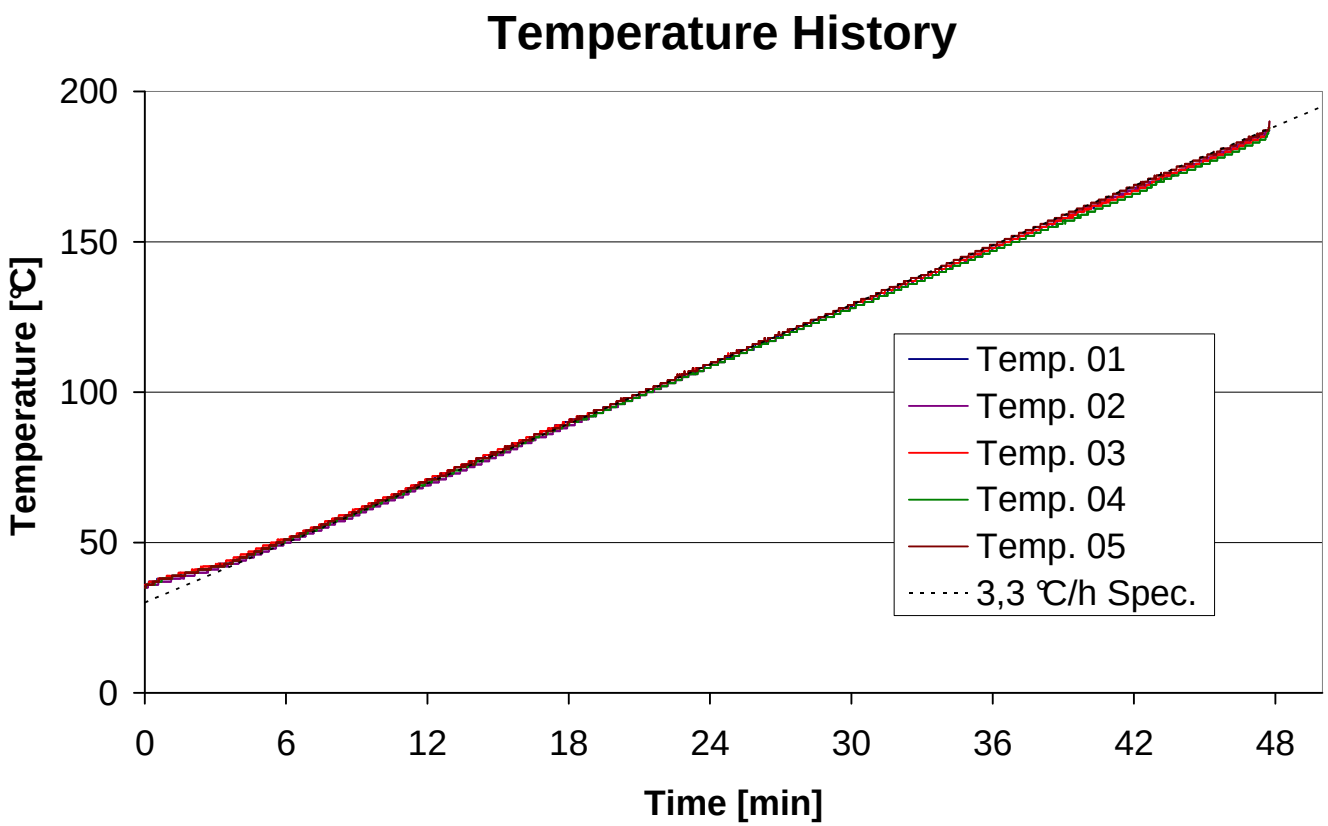
Full-scale IM Demonstration

- Two candidate formulations tested in analogue warhead
  - RXHR-6 (RDX-based)
  - HXHR-1 (HMX-based)
- One formulation selected and tested in fragmentation warhead
  - RXHR-6
- Tests conducted
  - Slow Heating
  - Liquid Fuel Fire
  - Bullet Attack
  - Fragment Impact

Slow Heating Test

- Standards
  - NATO STANAG 4382
  - MIL-STD 2105 B
- Heating apparatus
  - Ceramic heating blanket (1 × 7 kW)
  - Thermally insulated
  - Heating rate 3,3℃/hour
- Instrumentation & audio-visual equipment
  - Thermocouples (4 × Type K)
  - Bikini gauges
    (2 arrays of 3 × Type B-I and 3 × Type B-II)
  - Pressure transducers (2 ×)
  - Video cameras (3 × VHS)

Slow Heating Test



- Energetic events
  - Bulkhead dislodged at 171 ℃
  - Ignition and non-violent burning of explosive at 188 ℃

Slow Heating Test

- Reaction Classification
  - Type V (burning)

Liquid Fuel Fire Test (Mini)

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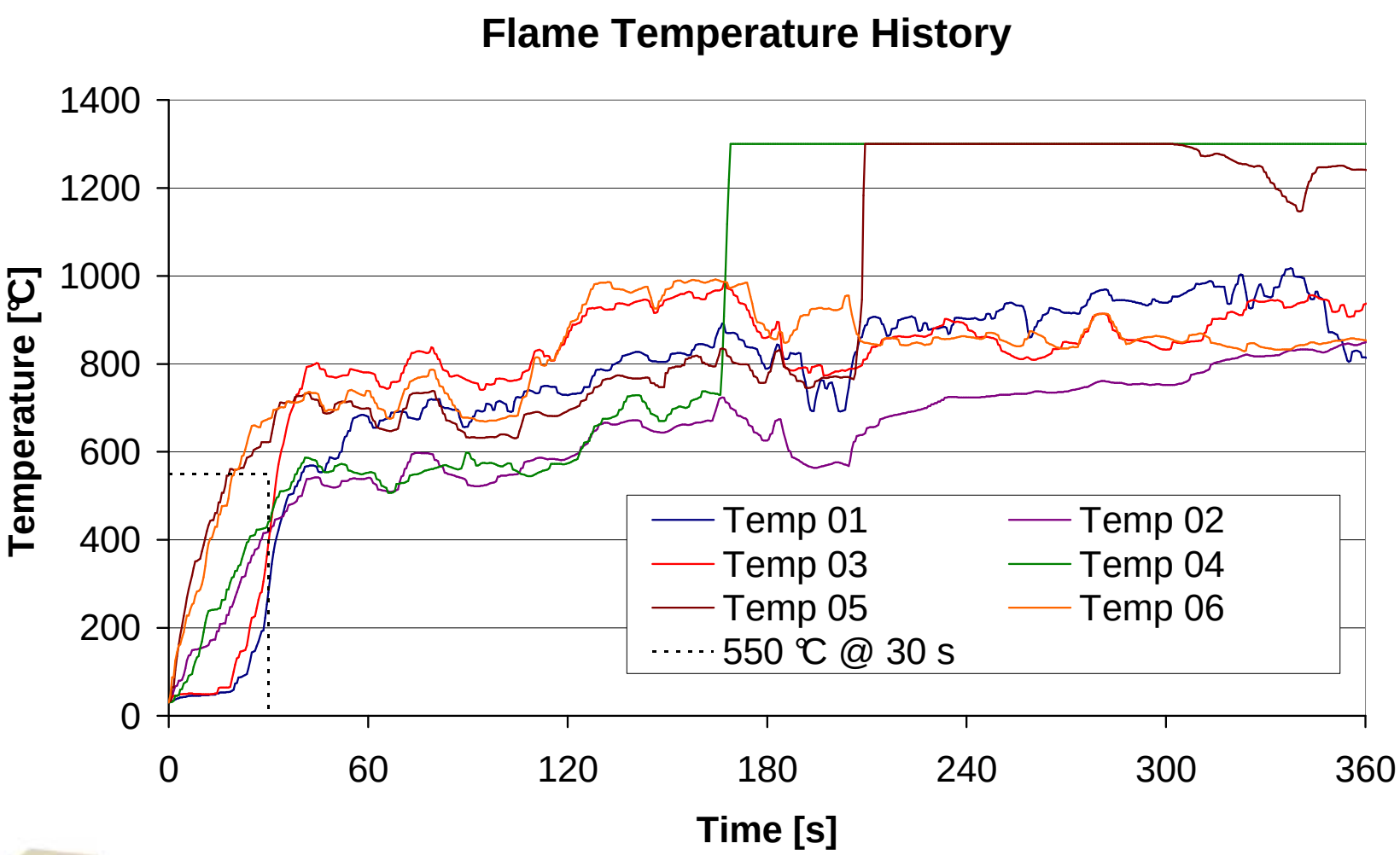
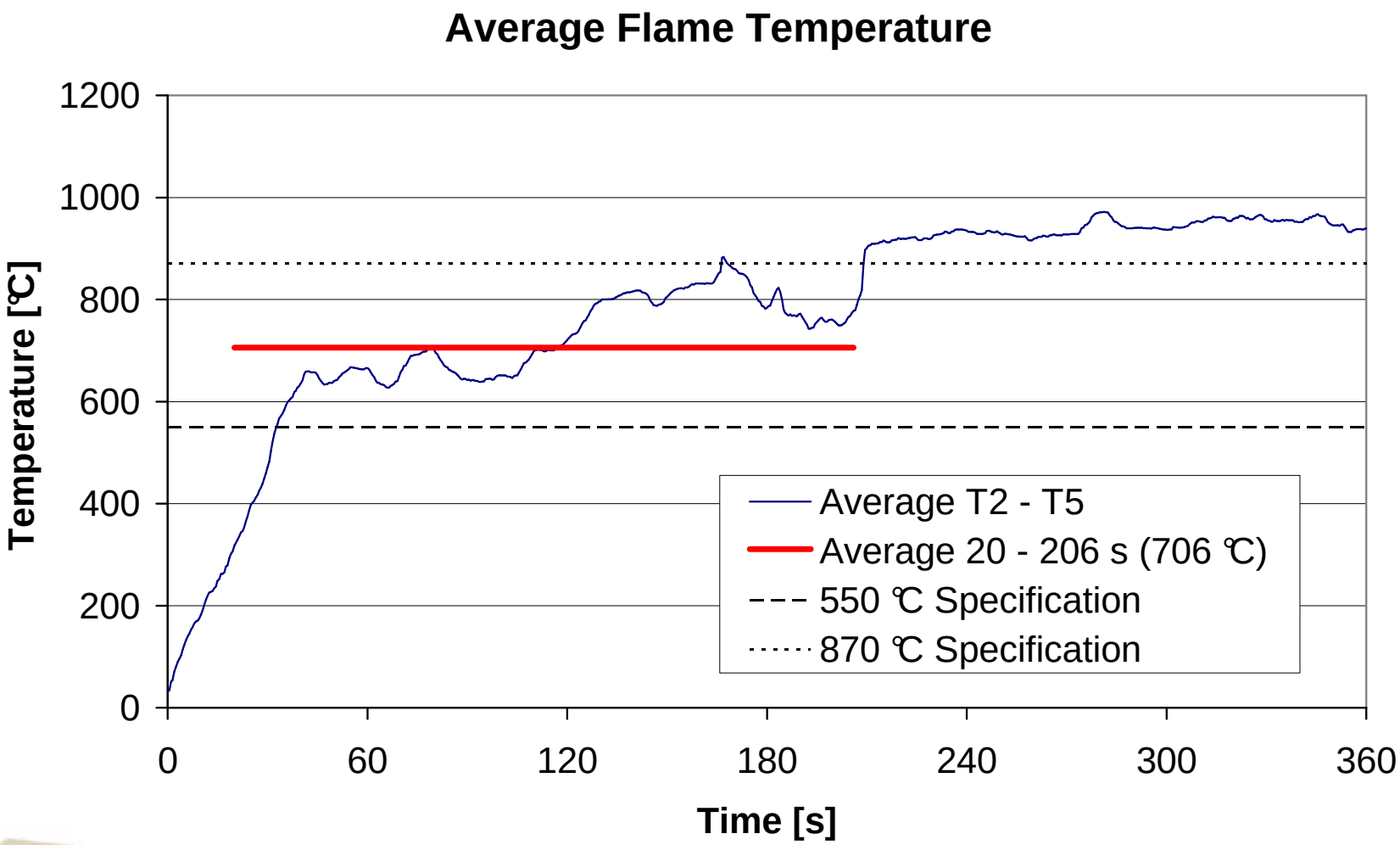
- Standards
  - NATO STANAG 4240
  - MIL-STD 2105 B
- Hearth
  - 3 × 200 litre containers
    (approximately 365 mm dia. × 2,4 m high)
- Instrumentation & audio-visual equipment
  - Thermocouples (6 × Type K)
  - Bikini gauges
    (2 arrays of 3 × Type B-I and 3 × Type B-II)
  - Pressure transducers (2 ×)
  - Video cameras equipped with microphones
    (2 × SVHS, 3 × VHS)
  - High-speed digital video camera (1000 fps)

Liquid Fuel Fire Test



Liquid Fuel Fire Test



Liquid Fuel Fire Test

- Energetic events
  - Both bulkheads were expelled (165 and 183 seconds after ignition of fuel)
  - Explosive ignited and burned non-violently (203 seconds after ignition of fuel)
- Observations
  - Bulkhead imprint on container
  - Molten aluminium casing on steel grid
  - Traces of exposed EM burning on steel grid
  - No overpressure measured
  - No fragmentation
- Reaction Classification
  - Type V (burning)

Bullet Attack Test

- Standards
  - NATO STANAG 4241
  - MIL-STD 2105 B
- Attack munition
  - 12,7 mm Amour Piercing
  - 850 m/s impact velocity
  - 20 m stand-off distance
- Instrumentation & Audio-visual Equipment
  - Bikini gauges
    (2 arrays of 3 × Type B-I and 3 × Type B-II)
  - Pressure transducers (2 ×)
  - Video cameras (2 × SVHS, 3 × VHS)
  - High-speed digital video (1000 fps)

Bullet Attack Test

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Bullet Attack Test

Debris mapping

Item Description	Distance [m]	Angle (from N)	Mass [g]
Front bulkhead	2,80	163 º	369
Compression disc	11,45	146 º	28
Outer sleeve half	16,50	193 º	~290
Outer sleeve half	7,15	236 º	~290
Booster half	2,70	112 º	~8
Explosive	0,45	13 º	~150
Explosive	0,90	66 º	~250

- Energetic events
  - Explosive burned non-violently
- Reaction Classification
  - Type V (burning)

Full-scale IM Evaluation Summary

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IM Classification Comparison of Warheads with Baseline and IM Formulations

Test	Warhead Configuration and Explosive Formulation			
	Baseline	Analogue Warhead		IM [1]
	RXCX-1	RXHR-6	HXHR-1	RXHR-6
Slow Heating	Type V	Type V	Type V	Type V
Liquid Fuel Fire	Type II	Type V	Type V	Type V
Bullet Attack	Type I	Type V	NR [3]	Type V
Fragment Impact [2]	Type I	NR [3]		

1. Identical warhead configuration to baseline apart from formulation
2. 16-gram cylindrical fragment with an impact velocity of 2000 m/s as reported by König and Smit, 2004 IM & EM Technical Symposium
3. No Reaction

IM Classification of Warhead with Baseline - and IM Formulations

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Baseline formulation RXCX-1

REACTION	TEST						
	Liquid Fuel Fire	Slow Heating	Bullet Attack	Fragment Impact	Spall Impact	Shape Charge Jet Impact	Sympathetic Reaction
I							
II							
III							
IV							
V							

IM formulation RXHR-6

REACTION	TEST						
	Liquid Fuel Fire	Slow Heating	Bullet Attack	Fragment Impact	Spall Impact	Shape Charge Jet Impact	Sympathetic Reaction
I							
II							
III							
IV							
V							

Conclusions

- A cost effective IM High Explosive was formulated.
- Performance requirement is met for both fragment distribution and penetration.
- Formulation is insensitive to mechanical *and* thermal stimuli as demonstrated by full-scale IM testing.