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

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ABSTRACT

Poor vulnerability properties of a conventional RDX-based Pressed PBX, RXCX-1, resulted in alternative, less vulnerable formulations being evaluated as possible replacement High Explosives. An RDX-based formulation, RXHR-6, originally developed as IM replacement to Composition A3 for application in high setback configurations, formed the basis of the formulation effort. An HMX-based analogue was evaluated in parallel to serve as a backup in the event of non achievement of predicted performance levels of RXHR-6 during full-scale arena testing.

Currently, full-scale IM testing (i.e. slow heating, fuel fire, bullet attack and fragment impact), as well as arena testing have been completed. Good results were achieved, with Type V reactions observed for all the IM tests. The system performance specifications were met during the arena test evaluation for fragment penetration and distribution. The latter results compared favourable with results of the conventional PBX obtained during qualification.

Granular product manufacture for RXHR-6 has been industrialised to 100-kg scale. Bulk density and angle of repose results were satisfactory, resulting in high densities (~99,5% TMD) being achieved during pressing. For full-scale evaluation, pellets were pressed with a 400-ton press, followed by machining to final dimensions.

INTRODUCTION

A paper titled *"Towards IM for High Setback High Explosives"*, presented by Denel at PARARI 2003, proposed RXHR-5 as IM alternative to Composition A3 for artillery charges. This formulation is closely related to formulations such as PBXN-9 and PBXW-17. The latter two formulations are well known as reduced vulnerability Pressed PBX's. However, the cost of PBXN-9 as well as some vulnerability issues relating to PBXW-17, necessitated development of a new formulation. Optimisation of RDX content, crystal size distribution, gap test sensitivity and manufacturing procedure culminated in RXHR-5. This formulation was industrialised to 100-kg scale and subsequently qualified according to the RSA Military Standard 154 as RXHR-6.

FORMULATIONS AND PERFORMANCE

RXCX-1, a Pressed PBX with 97% (m/m) RDX and 3% cariflex binder, was previously qualified as main warhead charge in an indigenous missile fragmentation warhead. With the introduction of IM requirements and an IM policy for South Africa, vulnerability assessment with RXCX-1 demonstrated poor IM characteristics, as was expected. Both the bullet attack and fragment impact test reactions were classified as Type I (detonation) and the fuel fire test reaction as Type II (partial detonation).

Two potential IM formulations were identified for further investigation. RXHR-6 and HXHR-1 were previously proven as formulations with reduced vulnerability properties. Both were plasticised Pressed PBX formulations with Hytemp 4454 as binder and both could be machined to the extent required. However, the lower energetic material content of both these formulations necessitated some calculations, modelling and experimental verification to prove that system performance will not be compromised.

Table 1: Performance properties of IM candidates compared to RXCX-1

Property	**Formulation**		
	RXCX-1	**RXHR-6**	**HXHR-1**
Density* (g/cc)	1,717	1,669	1,765
VOD $_{exp}$ (m/s)	8440	8247	8586
VOD $_{calc}$ (m/s)	8452	8224	8575
P (kbar) $_{calc}$	305	284	325
P (kbar) $_{BKW}$	297	273	299
VOD $_{BKW}$ (m/s)	8313	8053	8302
Gurney Energy $_{BKW}$ (m/s)	2765	2709	2756

* Typical pressed densities are given. In addition, it should be noted that the IM candidates can be pressed to a higher %TMD (Theoretical Maximum Density) than the conventional PBX.

It is noteworthy that the calculated detonation velocities are in good agreement with experimental results. VOD values obtained by computer simulation are lower, leading to expectations of somewhat larger Gurney velocities in practice. In fact, preliminary experimental results indicated only a marginal difference, 2784 m/s being obtained for RXCX-1. Thus the Gurney velocity values in Table 1 were used for an effectiveness study. The study concluded that the system performance requirements would be met at a Gurney velocity 3% lower than the BKW generated result for RXHR-6. It was decided to confirm this prediction with full-scale static testing of warheads containing RXHR-6.

Henceforth, the fragment distribution and penetration were determined for comparison to the baseline warhead (RXCX-1 as main charge) performance and specifications. As a prerequisite, the reliability of detonation transfer between booster and main charge was verified. The choice of booster was HSKF 9001 (HNS based), previously proven to be suitable for IM applications.

The fragment distribution was obtained by means of witness plates and the fragment penetration by target plates. In all of the angular intervals, where the specifications are concerned, the minimum requirement of 80% perforation were met. For fragment distribution, the results were in general very similar to that of the pre-qualification and qualification shots. In conclusion, the first IM requirement considered, that is not to compromise performance, was met with an RXHR-6 filled warhead.

As mentioned, the vulnerability assessment results obtained with RXHR-6 in other configurations were good. Large-scale gap test comparisons also proved it to be considerably less sensitive than RXCX-1. Values for a 50% probability of initiation transfer are indicated in Table 2.

Table 2: Large-scale gap test results

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

This test consists of unconfined donor and acceptor charges measuring 38 mm in diameter and 60 mm in length. CH-6 is used as the donor charge and Perspex as the gap filler.

Expectations were to pass the identified vulnerability assessment tests.

FULL-SCALE IM CHARACTERISATION

Full-scale IM characterisation, including slow heating, liquid fuel fire, bullet attack and fragment impact, was conducted with both IM candidate formulations on an analogue warhead.

Subsequent full-scale tests conducted on the fragmentation warhead containing an 8-kg charge of the RXHR-6 formulation are described in the following paragraphs.

Slow Heating Test

The slow heating test was conducted in accordance with the requirements of STANAG 4382, Edition 1. The test item was positioned with its major axis vertically on a steel suspension frame. The test item was heated by means of an insulated single-phase ceramic band heater.

Figure 1: Slow heating test set-up

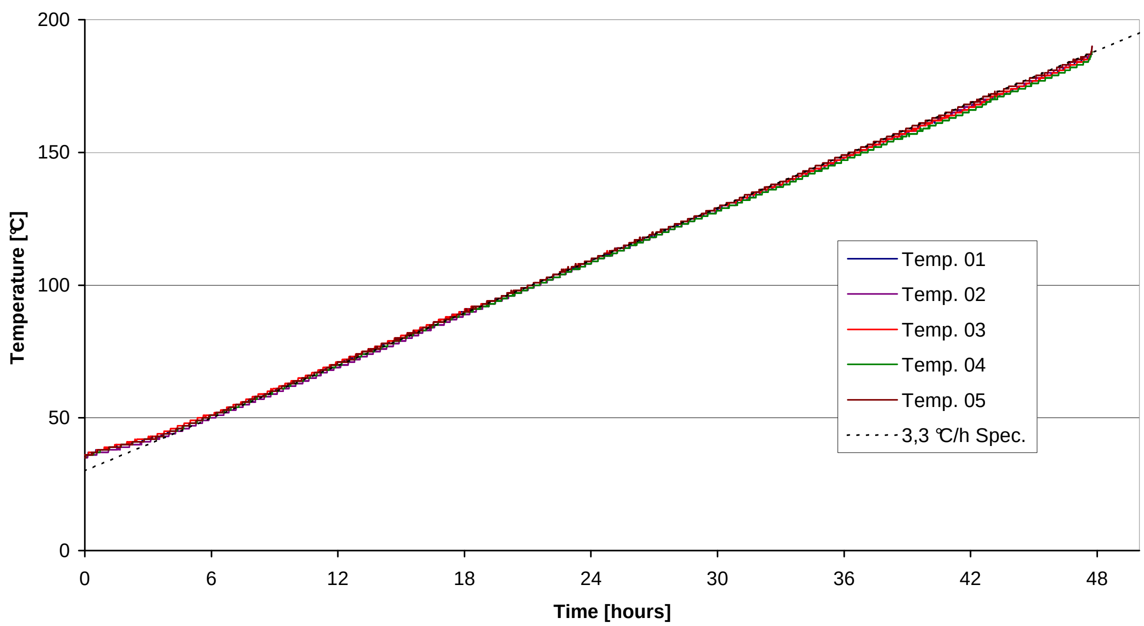

Figure 2: Temperature history for slow heating test

The required 3,3 ºC/h heating rate was maintained for the duration of the test. The first event occurred at 171 ºC when the lower (rear) bulkhead was dislodged. At 187 ºC the test item was pushed upward, probably due to molten explosive emitting from the unit, followed by ignition and burning of the explosive at 188 ºC. The insulation at the upper (forward) bulkhead was still intact.

Figure 3: Slow heating test result

The reaction was classified as Type V (burning).

Liquid Fuel Fire Test

The liquid fuel fire test was conducted in accordance with the requirements of STANAG 4240 Edition 1. Although a 6 × 6 metre hearth is required by the standard, such area is intended for testing integral munitions and a smaller set-up was devised for testing the warhead subsystem only.

The hearth comprises of three 200-litre containers, 565 mm in diameter, providing a flame envelope that completely engulfs the test item throughout the test. The test item was positioned on the steel grid in the centre of the hearth with its major axis orientated horizontally and front bulkhead to the right (viewed from inspection hole).

Approximately 75 litres of water is poured into the hearth to ensure that the fuel level approximates the correct distance below the test item. 35 litres of Jet A-1 fuel is used with an expected total burn time in the order of 20 minutes. The test item was approximately 680 mm above the initial fuel surface.

Figure 4: Liquid fuel fire test set-up

The temperatures recorded during the test are presented in Figure 5. Three energetic events were audible, at 165 s, 183 s and 203 s after ignition of the fuel. The container was dented markedly to the right of the inspection hole (at the front bulkhead side) following the second event, indicating possible expulsion of the bulkhead. Thermocouple readings at positions No. 4 and 5 (to the right and behind the item as viewed from the inspection hole) were affected at the first and third events respectively. While thermocouple No. 4 was damaged, thermocouple No. 5 was merely subjected to temperatures exceeding the saturation value of 1300 ºC (presumably due to burning explosive), as evidenced by the recovery reading following 305 seconds.

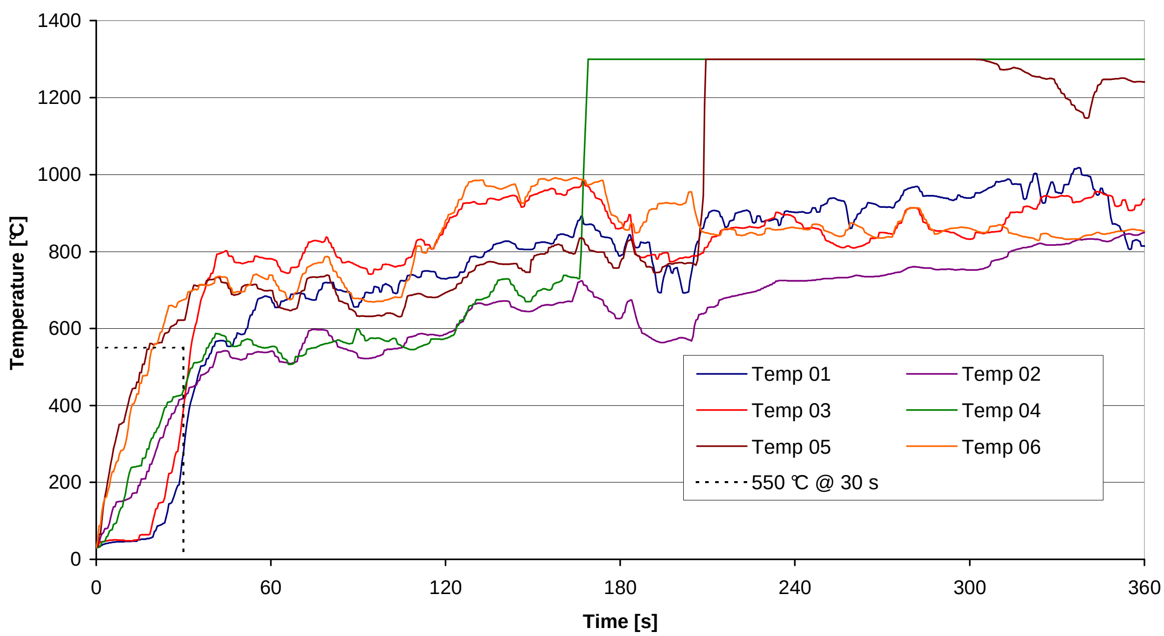

Figure 5: Temperature history for liquid fuel fire test

Signs of the steel grid being subjected to a localised excessive heat source behind the test item (viewed from the inspection hole) are observed, indicating that some exposed explosive material was probably burning in this area. A bulkhead imprint was also witnessed on the container to the right.

Figure 6: Hearth after liquid fuel fire test

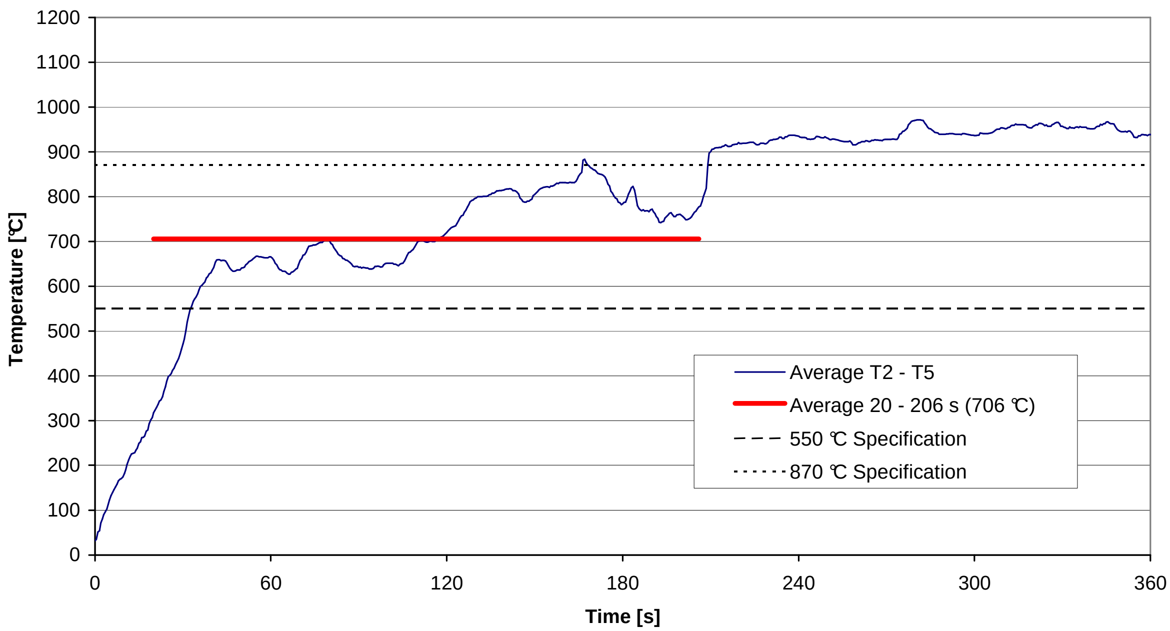

Figure 7: Average flame temperature for liquid fuel fire test

The average flame temperature as determined for thermocouple No.'s 2 through 5 (i.e. all readings excluding thermocouples above and below the test item) from T_0 (at 20 seconds) to the main event (at 206 seconds approximately) are plotted in Figure 7. The 706 ºC falls short of the 870 ºC specification and could be ascribed to exceedingly windy conditions during the test. However, this deviation does not necessarily compromise the validity of the test.

It is uncertain whether the bulkheads would have been projected beyond the 15-metre limit, had the test been conducted in an open hearth. However, it should be noted that expulsion of the bulkheads would be limited to the adjacent subsystems in the missile configuration and a Type V reaction would be appropriate.

Bullet Attack Test

The bullet attack test was conducted in accordance with the requirements of STANAG 4241, Edition 1. The front interface of the test item was attached to a suspended frame with its axis vertical, while the frame was anchored to a reinforced concrete slab.

The attack munition was a 12,7 mm × 99 AP round, fired from a gun that was rigidly mounted at a 20-metre standoff distance from the test item. The point of aim coincided with the approximate centre of the explosive.

Figure 8: Bullet attack test set-up

A contact screen arrangement was positioned adjacent to the test item to determine the bullet impact velocity. Any blast over-pressure would be measured by pressure transducers and bikini gauges positioned at discrete locations.

The bullet impact velocity measured was 894,5 m/s. The charge ignited and burned non-violently after impact of the bullet.

Figure 9: Bullet attack test result (unreacted explosive visible in foreground)

The debris was mapped as listed in Table 3.

Table 3: 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

Apart from one half of the outer sleeve found beyond the Type V periphery (by a mere 1,5 metres), all observations and measurements indicate a mild reaction. This deviation is regarded as marginal, especially considering that the sleeve is a lightweight component and that it is unlikely that personnel would suffer injury at a distance of 15 metres.

IM Full-scale Evaluation Summary

The full-scale IM test results conducted on both analogue and fragmentation warheads are summarised in Table 4 and compared to results obtained with a fragmentation warhead containing the baseline cariflex formulation.

Table 4: IM classification comparison of warheads with baseline and IM formulations

Test	Warhead Configuration and Explosive Formulation			
	Baseline*	Analogue Warhead		IM*
	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	Type V	Type V
Fragment Impact**	Type I	Type V	-	-

* Identical warhead configuration apart from formulation

** 16-gram cylindrical fragment with an impact velocity of 2000 m/s as reported by König and Smit, 2004 IM & EM Technical Symposium

CONCLUDING REMARKS

Considering that only one test was conducted for each formulation in the applicable analogue or tactical configuration, the available test data is too limited to present any statistical significance. Taking into consideration the high cost of test items and full-scale evaluation, this will probably be the case for most, if not all, tactical missile systems.

However, the selected formulation was subjected to two tests in similar configurations and none of the tests indicate that a more violent response than a Type V reaction is to be expected. The fact that the response violence of the warhead was alleviated to an acceptable level for both mechanical and thermal stimuli is quite remarkable. Moreover, the performance requirements are still satisfied as demonstrated.

It is recommended that further IM testing be conducted to assess munition vulnerability against the whole spectrum of threats, such as shaped charge jet impact, unless a comprehensive Threat Hazard Analysis signify that these threats are not applicable for the total lifecycle of such systems.