2010 Insensitive Munitions and Energetic Materials Technology Symposium
Munich, Germany, October 11-14, 2010

IMX-104 Characterization for DoD Qualification

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ABSTRACT

The U.S. Army, Armament Research, Development and Engineering Command (ARDEC) at Picatinny Arsenal, New Jersey, is working in conjunction with BAE Systems Ordnance Systems Inc. on the development of a production scale process for the manufacture of the high explosive IMX-104. This new melt castable explosive is a replacement of the traditional Composition B legacy explosive. IMX-104 shows improved shock and IM response as compared with the traditional explosive fills. The new composition, IMX-104, is currently being evaluated for the M821A2, M889A2, & m889A1 81mm Mortars, the M720A1, M768, and M888 60mm Mortars, the M934A1 120mm Mortar, the M2A4 15 lb Shaped Charge, and the Bangalore Torpedo.

The Explosives Development Branch is currently leading the effort to qualify IMX-104 explosive formulation for use in Joint Service items.

BACKGROUND

The Project Manager for Combat Ammunition Systems (PM-CAS) developed the Common Low-cost IM Explosive (CLIMEx) program to identify an affordable common IM HE fill to replace both TNT and Comp B. Twenty-three (23) explosive candidates developed by domestic and international industries, as well as government agencies, were evaluated. Both initial characterization testing and engineering level IM testing were conducted, and while one common HE fill could not satisfy the requirements for both TNT and Comp B, the program was successful by attaining two IM replacement formulations: IMX-101 to replace TNT and IMX-104 to replace Comp B. These formulations not only performed very well in the IM tests, but each also met the performance requirements applicable to TNT and Comp B loaded rounds. Based on these impressive results, IMX-104 is undergoing Energetic Materials Qualification as well as an Engineering Change Proposal (ECP) for qualification in the 81mm HE Mortars, 60mm HE Mortars and 120mm HE Mortars. In addition to PM-CAS, support for the qualification of IMX-104 has also come from PEO Ammunition and the OSD Joint IM Technical Program (JIMTP).

IMX-104 is a melt castable explosive and, to date, more than 70,000 pounds (lbs.) have been produced using manufacturing level processes at BAE Systems OSI - Holston Army Ammunition Plant (HSAAP). The formulation contains dinitroanisole (DNAN), 3-nitro-1,2,4-triazole-5-one (NTO) and RDX. Lot BAE09E-408-003 has been chosen to undergo all qualification testing that is required by the following test protocols to ensure that each new energetic material is deemed safe and suitable for its intended use:

Allied Ordnance Publication Seven (AOP-7) (Edition 2 Rev. 3), "Manual of Data Requirements and Tests for the Qualification of Explosive Materials for Military Use", December 2007.

Standardization Agreement (STANAG) 4170 (Edition 3), "Principles and Methodology for the Qualification of Explosive Materials for Military Use", 2007.

DoD Energetics Qualification Program Matrix for Main Charge Explosives

This report contains the experimental results of the following IMX-104 qualification tests: ERL/Bruceton Impact, BOE Impact, BAM Friction, ARL Friction, Small-Scale Electrostatic Discharge (ESD), Vacuum Thermal Stability (VTS), Ignition and Unconfined Burning, Variable Confinement Cook-Off test (VCCT), Differential Scanning Calorimetry (DSC), and the One-Liter Cook Off Test. Final tests for the qualification of IMX-104 are still underway.

QUALIFICATION TESTING

Sensitivity Tests

The ERL/Bruceton Impact test, the BOE Impact test, the BAM friction test, the ABL friction test, and the small-scale electrostatic discharge (ESD) testing of IMX-104 were performed on the baseline IMX-104 material. Testing standards are provided in the following documents:

The ERL, Type 12 Impact Sensitivity Test is described in STANAG 4489 Ed. 1 "Explosives, Impact Sensitivity Tests".

The Bureau of Explosives (BOE) Impact Sensitivity Test is described in the Department of Defense Explosives Hazard Classification Procedures; ARMY TB 700-2 dated 5 January 1998. It is also described in MIL-STD-1751A, dated 11 December 2001, Method 1011, "Impact Test (Laboratory Scale) – Bureau of Explosives Apparatus".

The Large BAM Friction Test Method is described in STANAG 4487 "Explosives, Friction Sensitivity Tests" and MIL-STD-1751A, dated 11 December 2001, Method 1024, "BAM Friction Test".

The ABL Friction Test Method is described in the Department of Defense Explosives Hazard Classification Procedures; ARMY TB 700-2 dated 5 January 1998.

The Electrostatic Sensitivity Test is described in MIL-STD-1751A, dated 11 December 2001, Method 1032, "Electrostatic Discharge Sensitivity Test (ARDEC (Picatinny Arsenal) Method)".

Samples were also aged at 60°C and 70°C and tested 1, 2, 3 and 4 months. The results of testing on aged samples, as well as initial time zero results are summarized in Table 1 (aged samples were not subjected to BOE Impact tests or ABL friction tests). IMX-104 shows a great improvement in sensitivity when compared to Comp B in the ERL/Bruceton Impact test. The BAM friction result for IMX-104 at time zero may be attributed to the friction sensitivity of DNAN, which reacts at 128N, but shows no reaction in 10 trials at 120N. Aging tests will also be conducted at 6 months on the 70°C aged samples, 8 months on the 60°C aged samples, and 12 months at 25°C and 30% relative humidity.

	Test Data	Explosive	Aging Time							
			0 Months	**1 Month at 60°C**	**1 Month at 70°C**	**2 Months at 60°C**	**2 Months at 70°C**	**3 Months at 70°C**	**4 Months at 60°C**	**4 Months at 70°C**
ERL/Bruceton Impact	50 % Impact Height (cm)	IMX-104	114.4	> 125.9	> 125.9	> 125.9	> 125.9	> 125.9	> 125.9	> 125.9
		RDX	18	-	-	-	-	-	-	-
		Comp B	33.9	-	-	-	-	-	-	-
BOE Impact	10 trials at 4 inch. drop height	IMX-104	No Reaction	-	-	-	-	-	-	-
		RDX	Reaction Observed	-	-	-	-	-	-	-
		Comp B	Reaction Observed	-	-	-	-	-	-	-
BAM Friction	10 TIL (N)	IMX-104	160	180	216	180	192	216	192	192
		RDX	168	-	-	-	-	-	-	-
		Comp B	168	-	-	-	-	-	-	-
ABL Friction	20 TIL (N)	IMX-104	4450	-	-	-	-	-	-	-
		RDX	1870	-	-	-	-	-	-	-
		Comp B	8000	-	-	-	-	-	-	-
Small Scale ESD	Joules	IMX-104	No Reaction at 0.25J	No Reaction at 0.25J	No Reaction at 0.25J	No Reaction at 0.25J	No Reaction at 0.25J	No Reaction at 0.25J	No Reaction at 0.25J	No Reaction at 0.25J
		RDX	Go @ 0.25J	-	-	-	-	-	-	-
		Comp B	No Reaction at 0.25J	-	-	-	-	-	-	-

Table 1: IMX-104 Sensitivity Test Data

Cap Sensitivity Test

The cap sensitivity test is designed to determine the sensitivity of an explosive to initiation by shock from a standard #8 blasting cap. For each cap test, the detonator is embedded perpendicularly into the top of the 80 mm (ID) x 200 mm (L) sample and initiated to determine if it will detonate. Three trials were conducted for this test. A diagram of the test setup may be seen in Figure 1.

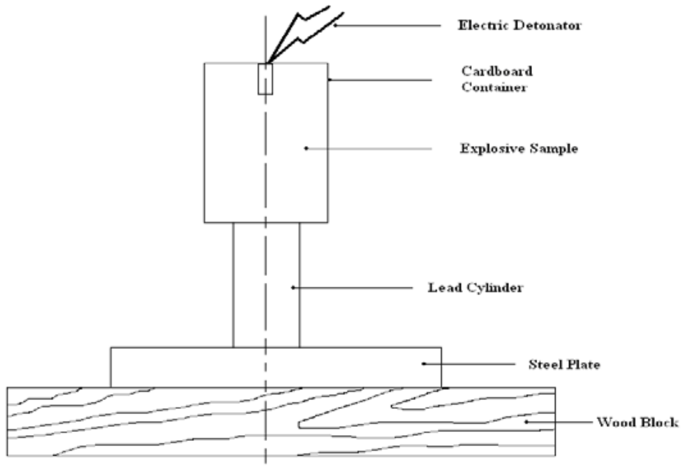

Figure 1: Cap Test Configuration

The requirement for IMX-104 is to be cap insensitive. Both RDX and Comp B will detonate when subjected to a #8 blasting cap detonator. During all three trials that were conducted on IMX-104, the samples did not detonate, thus passing the cap sensitivity test.

Vacuum Thermal Stability

Vacuum stability test was performed in accordance to STANAG 4556. The procedure measures the stability of an explosive at an elevated temperature (100°C) under vacuum for 40 hours. Testing of IMX-104 indicated only 0.571 ml gas per gram was generated, well within the 2 ml/g requirement to consider a substance stable. Table 2 summarizes VTS results for IMX-104 compared to RDX and Comp B.

	IMX-104	RDX	Comp B
Avg. Gas Evolution (ml / g)	0.571	0.12	0.602

Table 2: Vacuum Thermal Stability Results

Ignition and Unconfined Burning

In this small-scale burn test, explosive samples are placed in a plastic beaker and located on a bed of kerosene-soaked sawdust. The sawdust is then ignited and reactions are recorded.

The test result is considered “positive” if the sample explodes, indicating that the substance is considered too dangerous for transport. Otherwise the result is considered negative. Two trials with 10g of IMX-104 and two trials with 100g of IMX-104 each resulted in negative responses. No explosions were observed.

Variable Confinement Cook-off Test

The variable confinement cook-off test (VCCT) is a small-scale slow/fast cook-off test that uses 60 grams of explosive. Figure 2 illustrates the VCCT assembly. Table 3 and Table 4 show slow and fast VCCT results, respectively, for IMX-104 and Table 5 shows baseline Comp B slow cook-off results for comparison. Figure 3 includes two photos from the IMX-104 fast VCCT, representing examples of burn and pressure rupture reactions, respectively. All of the VCCT test results for IMX-104 were pressure ruptures or deflagration reactions, while the reactions for Comp B were much more violent, including explosions and detonations.

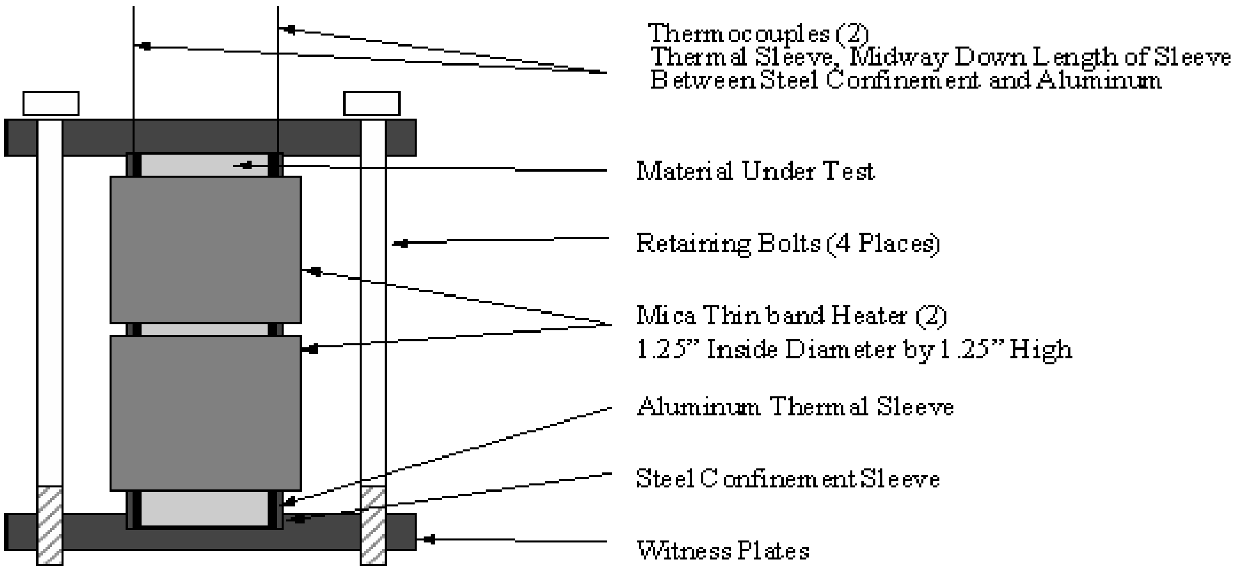

Figure 2: VCCT Assembly

Test Number	Steel Confinement (inch)	Time (minutes)	Reaction Level
1	0.075	7	Pressure Rupture
2	0.090	8	Pressure Rupture
3	0.105	9	Deflagration
4	0.120	11	Pressure Rupture

Table 3: IMX-104 VCCT Fast Cook Off Test Results

Test Number	Steel Confinement (inch)	Time (hours)	IMX-104 Reaction Level
1	0.075	12	Deflagration
2	0.090	19	Deflagration
3	0.105	28	Deflagration
4	0.120	17	Pressure Rupture

Table 4: IMX-104 VCCT Slow Cook Off Test Results

Test Number	Steel Confinement (inch)	Comp B Reaction Level
1	0.015	Explosion
2	0.030	Explosion
3	0.090	Explosion
4	0.120	Detonation

Table 5: Comp B VCCT Slow Cook Off Test Results

Figure 3: VCCT Fast Cook Off Test Results: 0.075 (pressure rupture) and 0.105 (deflagration)

Differential Scanning Calorimetry (DSC)

This test was conducted in accordance with STANAG 4515. The IMX-104 sample was subjected to a 5°C / minute ramping rate up to 300°C. The graph of IMX-104 baseline DSC can be seen below in Figure 4. The endotherm was evaluated to be 89°C, while the onset exotherm temperature was 212°C and the peak exotherm temperature was 224.89°C.

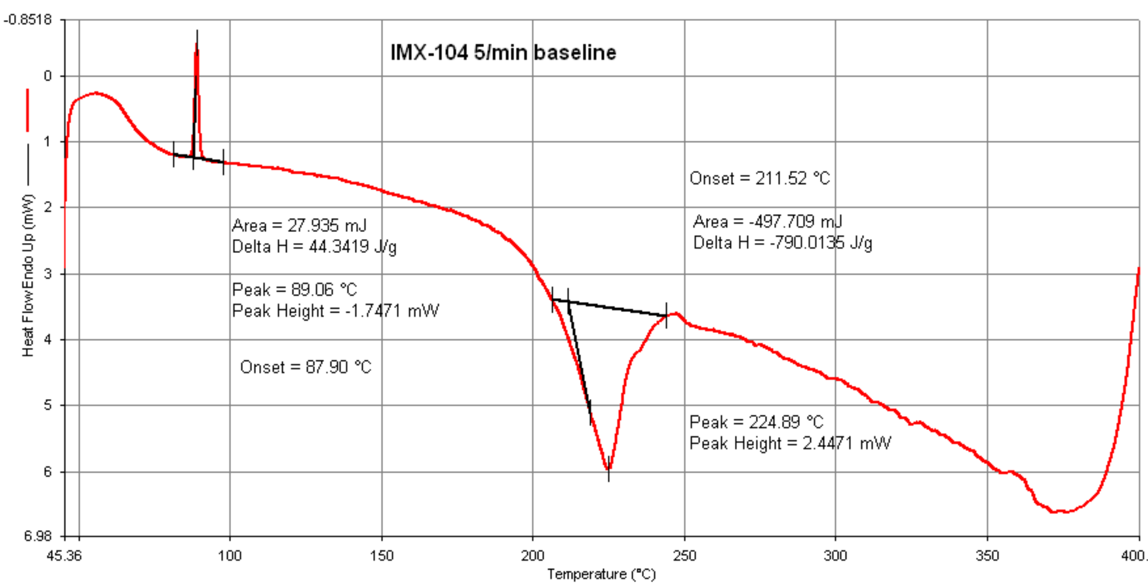

Figure 4: IMX-104 DSC

In addition to the baseline, IMX-104 was aged at 60°C and 70°C and DSC was performed at 0, 1, 2, 3, 4, 6, and 8 months. A 12 month aged IMX-104 sample at 25°C was also completed. All of these results are summarized in Table 6. The IMX-104 sample did not exhibit any significant or unordinary changes of decomposition in relation to its chemical composition. This is to be considered a pass. For comparison, the DSC results for RDX and Comp B have also been provided.

Explosive	DSC	Aging Time and Temperature										
		0 Months	**1 Month at 60°C**	**1 Month at 70°C**	**2 Months at 60°C**	**2 Months at 70°C**	**3 Months at 70°C**	**4 Months at 60°C**	**4 Months at 70°C**	**6 Months at 70°C**	**8 Months at 60°C**	**12 Months at 25°C & 30% RH**
IMX-104	Endotherm Temp.	89°C	89°C	90°C	90°C	89°C	89°C	89°C	89°C	89°C	89°C	89°C
	Exotherm Onset Temp.	212°C	222.96°C	216.22°C	220.96°C	210.02°C	211.03°C	215.25°C	213.98°C	212.52°C	217.57°C	215.42°C
	Exotherm Peak Temp.	224.89°C	232.89°C	224.89°C	231.22°C	229.22°C	234.78°C	228.27°C	229.69°C	228.07°C	231.44°C	230.10°C
RDX	Endotherm Temp.	205°C	-	-	-	-	-	-	-	-	-	-
	Exotherm Onset Temp.	210°C	-	-	-	-	-	-	-	-	-	-
	Exotherm Peak Temp.	241°C	-	-	-	-	-	-	-	-	-	-
Comp B	Endotherm Temp.	75°C	-	-	-	-	-	-	-	-	-	-
	Exotherm Onset Temp.	202.14°C	-	-	-	-	-	-	-	-	-	-
	Exotherm Peak Temp.	228.66°C	-	-	-	-	-	-	-	-	-	-

Table 6: Aged IMX-104 DSC results

One Liter Cook-off Test

In the one liter cook-off test, IMX-104 was placed in a one liter glass flask within a disposable plywood oven. The 1350g sample was soaked at 107°C for 6.5 hours and then subjected to a heating rate of 3.3°C / hour. Thermocouples as well as a camera documented the reaction of the IMX-104 as the temperature increased. The non-catastrophic self heating temperature (NCSH) was observed to be between 142°C and 144°C while the catastrophic self heating temperature (CSH) was determined to be between 161°C and 163°C. Approximately one hour after the material reached the CSH temperature, the IMX-104 reached 169.3°C and expanded over the one liter funnel attached to the flask and flows over the top for approximately 10 seconds before the material reacts. The final reaction of the material was to combust into a fireball burning for 1-2 seconds. Upon inspecting the remnants of the test, the oven and flask were still intact. There was not significant damage to the test setup.

These results (CSH temperature = 161°C to 163°C) validate the F-K (Frank Kamenetskii eq) model, which predicted the critical temperature (Tc) at which self heating begins for IMX-104 would be 164°C. This model is based upon conduction, assuming a thermal gradient from the center of the flask towards the surface, with the onset of self heating beginning at the center of the container. Figure 5, 6 and 7 show the test setup and appearance during the test.

Figure 5 – One Liter Cook-off test setup and appearance of IMX-104 at test start

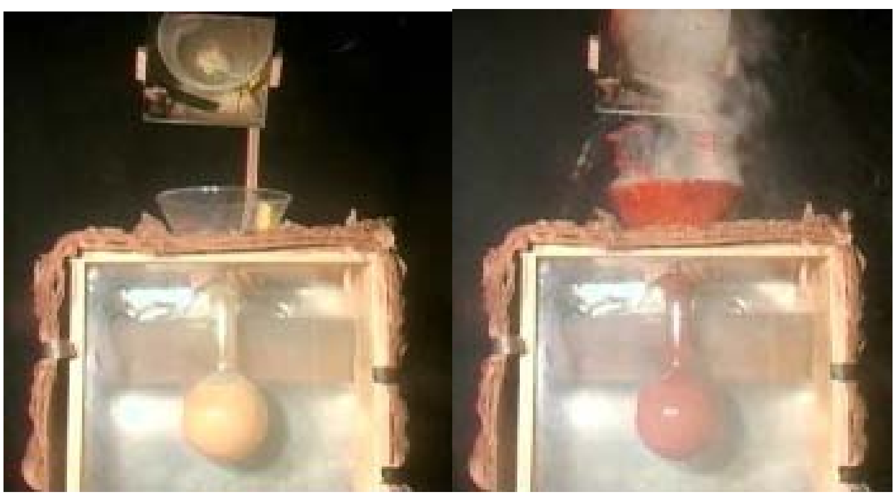

Figure 6 – IMX-104 at NCSH 141.3°C (left) & IMX-104 at 169.3°C, just before reaction (right)

Figure 7 – One Liter Cook Off Test Apparatus after final reaction of IMX-104

SUMMARY

Based on the successful selection of IMX-104 to replace Comp B through the PM-CAS CLIMEx program, explosive qualification testing of IMX-104 has provided significant sensitivity, stability, and safety information. The information reported in this paper along with results of the remaining qualification tests will enable the PM-CAS and the US Army to qualify and field safer IM rounds without reducing performance.

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