DEVELOPMENT AND MANUFACTURE OF AN INSENSITIVE COMPOSITION B REPLACEMENT EXPLOSIVE IMX-104 FOR MORTAR APPLICATIONS

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1. ABSTRACT

BAE SYSTEMS Ordnance Systems Inc. (OSI) had been involved in the development of melt-cast explosive formulations for consideration in the U. S. Army's selection process for a common Insensitive Munition (IM) explosive fill for mortar ammunitions. As part of the U.S. Army Project Manager Combat Ammunition Systems (PM-CAS) Common Low-cost IM Explosive (CLIMEx) program, this main objective was to develop a common IM explosive fill to replace Composition B for the 60mm, 81mm and 120mm mortar munitions.

Following the successful development and manufacturing of IMX-101 as an insensitive TNT replacement explosive fill for artillery ammunitions, BAE SYSTEMS developed an insensitive DNAN based melt pour explosive IMX-104 (previously known as OSX-7) as one of the candidates for evaluation in the CLIMEx program for mortar ammunitions. In extensive evaluation of both IM properties and energetic performance, the IMX-104 satisfied all requirements outlined by the U. S. Army. As a result, IMX-104 was down-selected as the lead candidate for an insensitive Composition B replacement and is currently undergoing full material qualification by the U. S. Army. To date, several batches of IMX-104 have been manufactured successfully in full production scale at Holston Army Ammunition Plant (HSAAP) with substantial production quantities of the explosive scheduled for later in the calendar year.

This paper details the technical approach in the lab scale development of IMX-104, the large scale production process development at HSAAP, and key chemical, physical, sensitivity properties of the explosive.

2. BACKGROUND AND OBJECTIVES

The main objective of the IMX-104 development program was to develop a common IM explosive to load into mortar ammunitions, replacing Composition B which was not compliant with IM targets. Composition B had been the explosive fill for the U.S. Army 81mm and 120mm Mortar Bombs for decades. The majority of mortar bombs currently used in theatre is loaded with Composition B, which is not considered as IM compliant explosive fill. Any Composition B replacement formulation would be required to demonstrate improved IM properties over Composition B, while not compromising energetic performance levels of the explosive. From the explosive manufacturing and bomb loading view point, it was also important that any candidate possess adequate processability, no worse than Composition B.

A secondary objective of the IMX-104 development program was to develop an insensitive explosive to replace PAX-21 for the 60mm Mortar. PAX-21 is a DNAN based insensitive melt pour explosive developed as an IM replacement for Composition B in the 60mm Mortar. Although significant improvement was achieved in IM properties, the performance level of PAX-21 was considerably less than Composition B. The inclusion of Ammonium Perchlorate (AP) in the PAX-21 formulation also caused major environmental concern. As part of the PAX-21 Product Improvement Program (PIP), the new insensitive explosive would not contain AP, and it would possess improved performance and IM response than PAX-21. Ultimately, the new insensitive explosive may potentially become a common fill for all mortar ammunitions (60mm, 81mm and 120mm).

One of the main goals for the formulation development program is to utilize ingredients manufactured on production scale at HSAAP, such as:

- Conventional Holston Ingredients: RDX and HMX
- Novel Insensitive Ingredients: DNAN, NTO, TATB, High Bulk Density NQ

HSAAP had been successful in the ingredients development and scale-up of the novel insensitive ingredients at the Agile Facility (Figure 1), as reported in previous IMEMTS. These insensitive ingredients had been proven to be inherently less sensitive than traditional high explosives and melt base ingredients.

Figure 1 The Agile Facility (Building G-10) at HSAAP

In the OSI selection process, potential candidates are evaluated in terms of performance (using performance prediction model), shock sensitivity (NOL Large Scale Gap Test), and processability (Efflux viscosity). The goals for the explosive candidates to achieve were:

Performance (Velocity of Detonation):	above 95% of Comp B
Shock Sensitivity (NOL LSGT):	50% card gap < 120 cards
Processability (Efflux viscosity):	less than 15 seconds at 96°C

3. FORMULATION DEVELOPMENT

3.1 METHODOLOGY

Performance prediction model (Cheetah v 4.0) calculation was conducted prior to experimental activities. Formulations that exhibited good potential in terms of velocity of detonation were then selected for small scale initial mixing trials. Visual appearance (viscosity and sedimentation) was observed. Promising candidates were then scaled-up so that accurate efflux viscosity measurement could be made. Finally, candidates with low efflux viscosity would be scaled-up to 20 LBS scale (for the loading of LSGT tubes). Formulations that passed the LSGT requirement (< 120 cards) were then selected as a candidate fill for the IM mortar program. Also, performance evaluation (Initiation Test) on candidates against Composition B was also conducted to ensure adequate level of performance was maintained.

3.2 FORMULATION CANDIDATES

Base on performance prediction modeling and past experiences, four formulation candidates were initially selected for preliminary evaluation. Two formulation candidates were then identified as potential Composition B replacement in terms of performance and processability for large scale loading operation. The details of the two formulation candidates, IMX-104 (previously known as OSX-7), and PAX-48 (now known as OSX-8), are given in Table 1. Both candidates are DNAN/NTO based formulations with different nitramine component: OSX-7 utilizes RDX and OSX-8 utilizes HMX.

Table 1 Typical Properties of IMX-104 and PAX-48 versus traditional mortar fillings

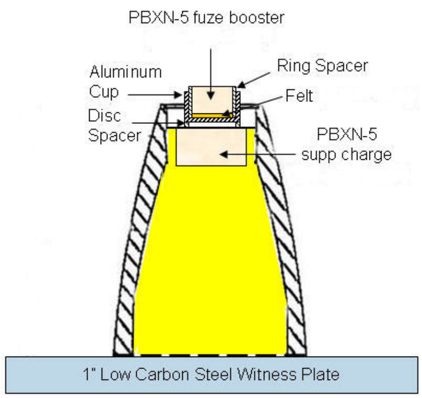
Material	Major Components	VOD (% Comp B)	LSGT (50% card gap)	MP/ Exotherm Onset (°C)	Efflux Viscosity @ 96°C (s)	Scale of Manufacture (lb / batch)
IMX-104	DNAN / NTO / RDX	98	118	89 / 213	< 10	1200 - 1500
PAX-48	DNAN / NTO / HMX	96	110	93 / 231	< 10	1200 - 1500
Comp B	RDX / TNT	100	207	80 / 215	-	1200 - 1500
TNT	TNT	84	133	-	-	1200 - 1500
PAX-21	DNAN / RDX / AP / MNA	83	161	89 / 193	< 10	1200 - 1500

From the processability (efflux viscosity) and hazard assessment (thermal / sensitivity), both IMX-104 and PAX-48 exhibited comparable or improved results when compare to the traditional mortar fillings such as Composition B and TNT, as well as newer formulation such as PAX-21. These results satisfied all the selection criteria for the insensitive formulation replacement for Composition B. Significant improvement in shock sensitivity was demonstrated by the Large Scale Gap Test results, where the 50% card gap for detonation had reduced from 207 cards to below 120 cards for both candidates.

3.3 PERFORMANCE COMPARISON

In order to evaluate the initiation and functioning properties of IMX-104 and PAX-48, both formulations were subjected to initiation and functioning tests in a 120mm Mortar ogive section. The top section of a 120mm Mortar contained approximately 1.8 lb of explosive. A single PBXN-5 fuze pellet, housed in standard fuze components such as felt and pellet container, and a single PBXN-5 booster pellet was used to initiate the test charge. A one-inch thick low carbon steel witness plate was placed below the test charge to gauge the level of performance. The trial set up is shown in Figure 2.

Figure 2 Initiation and Function Test Hardware and Set Up



Both IMX-104 and PAX-48 achieved high order detonation, in a similar manner to Composition B. A clean hole with diameter similar to the 120mm Mortar ogive section was found on all candidates. Photos of the pre and post initiation test can be found in Figure 3, 4 and 5.

Figure 3 Initiation and Function Test of IMX-104

Figure 4 Initiation and Function Test of PAX-48

Figure 5 Initiation and Function Test of Composition B

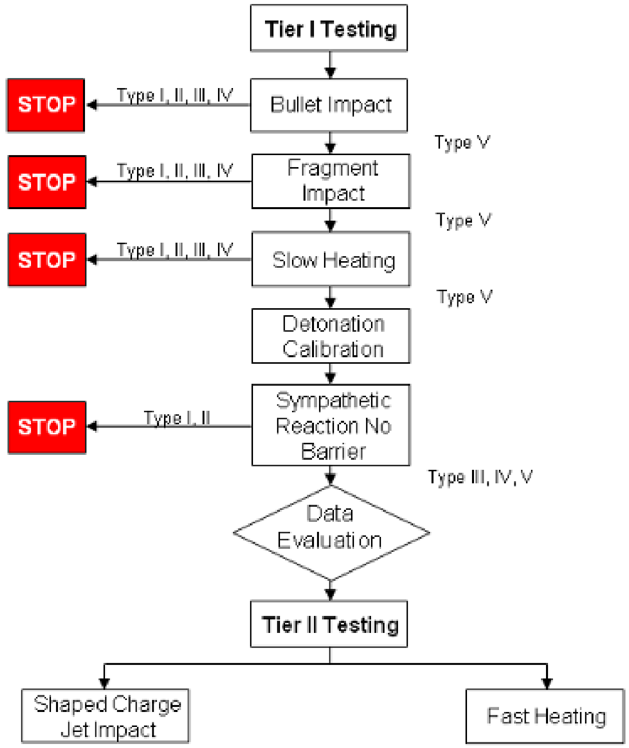
3.4 DOWN SELECTION FOR SCALE-UP

Based on the positive result on both performance and sensitivity for both IMX-104 and PAX-48, both candidates were down selected for manufacturing scale-up at the HSAAP production facility. Material generated from the scale-up (1200 lb each) were sent to U.S. ARMY PM-CAS for system scale IM Evaluation in 81 and 120mm mortar ammunitions. The large scale manufacturing of IMX-104 will be discussed in Section 5 of this paper.

4. IM ASSESSMENT TESTING IN MORTAR AMMUNITIONS

IMX-104 and PAX-48 was down-selected as OSI's candidates for the U.S. ARMY PM-CAS Common Low-cost IM Explosive Program (CLIMEx) Phase 2: Explosive Replacement for Composition B. The background and details of the program was reported at the last IMEMTS 2009 at Tucson, AZ [1] and test matrix from the IM Mortar Systems test is summarized in Figure 6.

Figure 6 IM Mortar System Test Matrix



In the IM Mortar System Test, IMX-104 managed to pass all the Tier 1 tests in 81mm and 120mm configuration, out-performing other formulation candidates, including PAX-48. As reported in the IMEMTS 2009, IMX-104 had been down-selected as the best candidate to replacement Composition B based on IM properties superiority, life cycle cost, lethality and production readiness. A summary and images of the IMX-104 IM Mortar System Test result can be found in Figure 7 and 8 respectively.

Figure 7 Summary of IMX-104 IM Mortar Systems Test Result

IM Test:	Fast Heating	Slow Heating	Bullet Impact	Fragment Impact	Sympathetic Reaction	Shaped Charge Jet Impact
Passing Criteria	V	V	V	V	III	III
81mm (Comp-B) Baseline	(II)*	(II)*	(III)*	(III)*	(I)*	(I)*
81mm (IMX-104)	V	V	12.7mm IV 7.62mm V	8300 ft/s III 6000 ft/s IV	III	I
120mm (Comp-B) Baseline	II	I	I	I	(I)*	(I)*
120mm (IMX-104)		V	IV	V	III	

Figure 8 Images of IMX-104 IM Mortar Systems Test Result

5. LARGE SCALE MANUFACTURING OF IMX-104

Since the down-selection of IMX-104 was made, a significant amount of IMX-104 was required to support the explosive qualification program (both material and system), as well as mortar loading trials. OSI, with the support from the US ARMY ARDEC process development team, had developed and optimized the large scale manufacturing process of IMX-104 in the melt pour explosive production facility at HSAAP.

5.1 MELT POUR EXPLOSIVE PRODUCTION PROCESS

Currently, all melt-pour explosive products such as IMX-101, IMX-104 and PAX-21 are manufactured utilizing the melt kettles and casting belt in Building L-4.

The facility consists of two, large-scale, 180-gallon, stainless steel steam jacketed melt kettles, a variable speed agitator, holding vessels, a conveyor belt for flaking, and nutsches for product (flake) collection. The capacity of each melt kettle varies between 1200-1500 pounds of product, depending on the product density.

In production scale manufacture of IMX-104, DNAN is added to the melt kettle (Figure 9) first. The temperature in the kettle is adjusted a temperature above the melting point of DNAN to allow the DNAN to melt and the residual moisture is subsequently removed. Slow agitation is applied to speed up the DNAN melting process. Once the DNAN is melted and the residual moisture removed, RDX and NTO are then charged into the melt kettle slowly. The kettle temperature is monitored closely at this stage as the addition of RDX and NTO into molten DNAN will reduce the mix temperature.

Figure 9 Production Scale Melt Kettle

Once all the ingredients are added, the agitator speed is increased to a higher level to allow adequate mixing inside the kettle (Figure 10). The material is mixed thoroughly for a fixed period of time until the product viscosity is judged to be satisfactory (adequate homogeneity); then the product is transferred from the melt kettle into a heated holding vessel in preparation for casting onto the flaker belt.

Figure 10 Mixing of IMX-104

Figure 11
Transfer of Product to Holding Vessel

The molten explosive is stored the holding vessel, where gentle agitation is applied to maintain homogeneity of the explosive. The molten explosive is then poured into a casting vessel before finally cast onto the flaker belt in strips (Figure 12) through several nozzles. The molten explosive is cooled and solidified as it travels on the flaker belt (Figure 13). At the end of the flaker belt, IMX-104 flakes are snapped and drop into a nutsche (Figure 14 and 15). The nutsche is then transported to a separate building for packing.

Figure 12 Casting of IMX-104 onto Flaker Belt

Figure 13 Flaker Belt

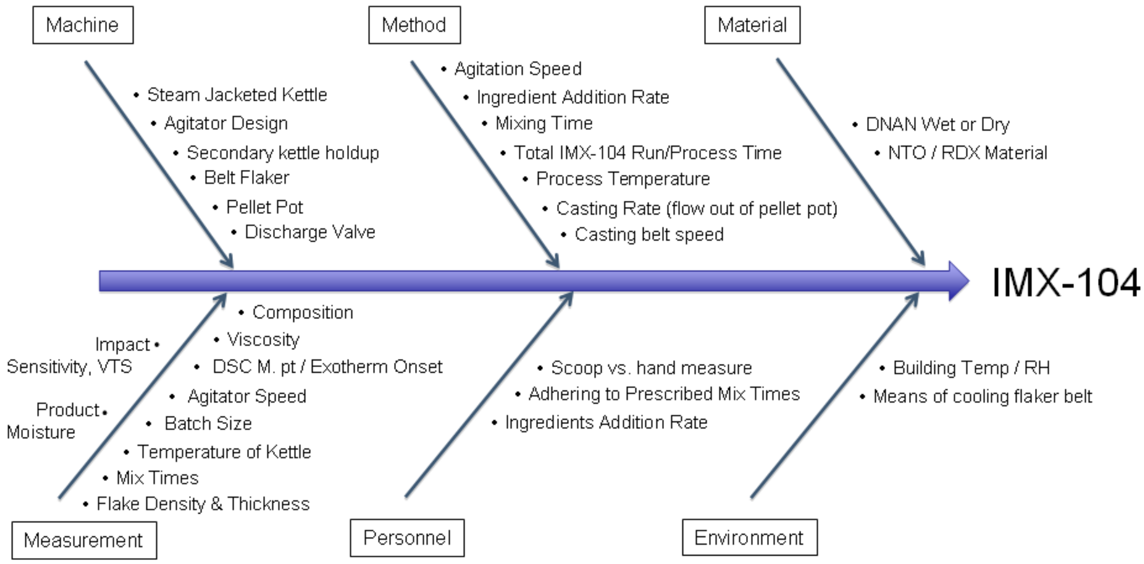
Figure 14 Product Flake Exit Belt

Figure 15 IMX-104 Flakes Collection in Nutsche

5.2 IMX-104 MANUFACTURING PROCESS DEVELOPMENT

The IMX-104 manufacturing process was developed and optimized following similar technical approach from previously developed formulations such as PAX-21 and IMX-101 [2]. First, all the major processing parameters which may influence the product quality have been identified. These processing parameters include processing temperatures at various stages, ingredient feed rate and order of addition, use of dry/wet ingredients, final incorporation (mixing) time and agitator speed (Figure 16). An assessment test matrix was set up based on past experience and equipment capability. IMX-104 batches were produced following the test matrix and product quality was evaluated in terms of processability (efflux viscosity), physical and thermal properties and product homogeneity (composition). OSI worked closely with the LAP and Producibility Teams at U.S. ARMY ARDEC during the process development activities. A robust and repeatable manufacturing process for IMX-104 had been developed which produces over 90,000 lb of consistent product to date.

Figure 16 IMX-104 Producibility Parameters Under Study



6. CONCLUSION

The successful development and manufacturing scale-up of IMX-104 is a major breakthrough in the effort to replace Composition B in all mortar ammunitions. IMX-104 had demonstrated excellent IM properties over Composition B under all level of threats face by war fighters around the world. IMX-104 is a relatively low cost replacement for Composition B as it utilizes existing manufacturing equipments in both mixing and high volume loading operations without any major investment in new technology and equipment.

In the search of a common fill explosive for all mortar ammunitions, IMX-104 had also demonstrated improved IM properties and performance over PAX-21, which is the current explosive fill for 60mm Mortar. IMX-104 can now be considered as the insensitive common fill explosive for the 60mm, 81mm and 120mm Mortar. IMX-104 is scheduled to be qualified as an insensitive explosive fill by Quarter 4 of 2010, closely followed by the system qualification of the 81mm Mortar by 2011, and the 60mm and 120mm Mortar by 2012.

IMX-104 is a truly remarkable insensitive Composition B replacement explosive. Although this paper is mainly focused on mortar application, it is believed that the IM achievement in this formulation can be applied to other weapon system such as demolition charges, various warheads, shaped charges and large bombs.

7. ACKNOWLEDGEMENT

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