Process Improvement and Optimization of Insensitive Explosive IMX-101

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Briefing Outline

• IMX-101 Explosive Overview
• Recent Manufacturing Achievement
• IMX-101 Process Improvement & Optimization
• Modernized Melt-Cast Explosive Manufacturing Facility at HSAAP
• Concluding Remarks
• Acknowledgements
IMX-101 Explosive Overview

- An insensitive melt-pour explosive to replace TNT for Artillery Projectile Applications
- IMX-101 and all starting ingredients manufactured at Holston Army Ammunition Plant
- Exhibited superior IM properties and comparable performance over TNT in 155mm M795 projectiles

<table>
<thead>
<tr>
<th>IM Test:</th>
<th>Fast Heating</th>
<th>Slow Heating</th>
<th>Bullet Impact</th>
<th>Fragment Impact</th>
<th>Sympathetic Reaction</th>
<th>Shaped Charge Jet Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>155mm M795 (TNT)</td>
<td>III</td>
<td>III</td>
<td>IV</td>
<td>IV</td>
<td>FAIL</td>
<td>FAIL</td>
</tr>
<tr>
<td>155mm M795 (IMX-101)</td>
<td>V</td>
<td>V</td>
<td>IV*</td>
<td>V**</td>
<td>PASS</td>
<td>PASS</td>
</tr>
</tbody>
</table>

* Passed original BI Test with one bullet through supp. charge, but failed (Type IV) with new test criteria of 3 bullets through supp. charge
** Main charge targeted

- IMX-101 qualified as an main fill explosive in Feb, 2010
- Achieved type qualification for the 155mm M795 projectiles in June, 2010
IMX-101 – Superior IM Performance

BULLET IMPACT (TYPE IV)

FAST HEATING (TYPE V)

SYMPATHETIC DETONATION (PASS)

SHAPED CHARGE JET IMPACT (PASS)

Photos courtesy of PM-CAS
A Family of Insensitive Melt Cast Explosive Formulations

Insensitive Melt Cast Explosives manufactured at Holston Army Ammunition Plant

<table>
<thead>
<tr>
<th>Formulation</th>
<th>Key Ingredients</th>
<th>Purpose</th>
<th>Qualification Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMX-101</td>
<td>DNAN + NTO + NQ</td>
<td>TNT replacement (for Artillery and other large caliber munitions)</td>
<td>Material qualified; Type qualified for 155mm M795, on-going for 155mm M1122 and 105mm projectiles</td>
</tr>
<tr>
<td>IMX-104</td>
<td>DNAN + NTO + RDX</td>
<td>Comp B replacement (for mortar applications)</td>
<td>Material qualified; Type qualification on-going for 81mm mortar, 60mm &amp; 120mm to follow</td>
</tr>
<tr>
<td>PAX-48</td>
<td>DNAN + NTO + HMX</td>
<td>Comp B replacement (for mortar &amp; tank ammunition)</td>
<td>Material qualified; Type qualification achieved for 120mm IM HE-T tracer round (NAMMO)</td>
</tr>
<tr>
<td>OSX-12</td>
<td>DNAN + NTO + RDX + Al</td>
<td>PAX-28 replacement (high blast applications)</td>
<td>Material under evaluation</td>
</tr>
<tr>
<td>PAX-21</td>
<td>DNAN + RDX + AP + MNA</td>
<td>Main fill for the 60mm M768 Mortar Rounds</td>
<td>Currently in-use in theater</td>
</tr>
<tr>
<td>PAX-41</td>
<td>DNAN + RDX + MNA</td>
<td>Main fill for the Spider Grenade</td>
<td>Currently in-use in theater</td>
</tr>
</tbody>
</table>
Recent Manufacturing Achievement

- Current batch size over 1200 lb. (~1500 lb. possible)
- Over 660,000 lb. manufactured at HSAAP to date (over 550 batches)
- Utilize existing equipment in the melt-pour explosive facility
- Robust and repeatable processes established for IMX-101, and the raw ingredients (DNAN, NTO, NQ)
- Optimization opportunities identified to reduce process cycle time & to improve process efficiency
- Modernized explosive manufacturing facility to be commissioned in Q4 2012
IMX-101 Process Improvement & Optimization Overview

- Objective: To maximize the manufacturing process efficiency of IMX-101 in order to lower unit cost while maintaining the desirable properties
  - Reduced cycle time
  - Improved product consistency
- Potential time saving measures identified through an internal Lean Six Sigma Black Belt project and presented to the IPT
- Implemented agreed optimization changes in a special IMX-101 manufacturing campaign
- Final products from optimized process underwent Conformity and First Article Testing to validate product quality
Current IMX-101 Manufacturing Process (1)
Current IMX-101 Manufacturing Process (2)

- Kettle Turn-Over time (from DNAN Charge to Removal of IMX-101 from Incorporation Kettle) ~ 415 minutes (6 hours 55 minutes)
- Once IMX-101 is removed from Incorporation Kettle, DNAN charge can commence for the next batch
- Three / Four batches (1207 lb) per 24 hours period
- Cannot satisfy future IMX-101 production requirement
Kettle Turn-Over Time Reduction Opportunities

• The current Kettle Turn-Over Time of 7 hours is excessive
• Areas identified for optimization relating to kettle turn-over time reduction:
  • NQ charging time reduction
  • NTO FEM and NTO regular charging time reduction
  • Final incorporation time reduction
  • Use of alternate vessel for melting DNAN (time consuming step in incorporation kettle)
    • DNAN Pre-Melter concept (Modernized Facility)
• Materials made from the optimized process must satisfy all FAT requirements (5 consecutive batches)
  • Impact & Friction Sensitivity, VTS; ELSGT (composite sample of 5 batches)
• Kettle Turn-Over time (from DNAN Charge to Removal of IMX-101 from Incorporation Kettle) ~ 300 minutes (from 415 minutes)
• Reduction of 115 minutes (1 hours 55 minutes) over current process
• Six/Seven batches (1207 lb) per 24 hours period possible
• Potential batch size increase to 1448 lb.
  • Design engineer confirms kettle capacity
Optimized IMX-101 Manufacturing Process (2)

- DNAN level checking
  - Level gauge enables the DNAN levels (composition) to be more consistent
  - Previously, the required level of DNAN was calibrated in the PAX-21 production campaign
  - Consistent DNAN compositions also improved consistency of NTO and NQ compositions
    - Mean values closer to nominal targets, lower SD (less variance) and higher process capability (Cpk value)

<table>
<thead>
<tr>
<th>Nominal Composition</th>
<th>Sample Size</th>
<th>Mean</th>
<th>SD</th>
<th>Cpk</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNAN (43.5%)</td>
<td>Previous 86 batches</td>
<td>43.034</td>
<td>1.228</td>
<td>0.490</td>
</tr>
<tr>
<td></td>
<td>Optimized Process (8 batches)</td>
<td>43.338</td>
<td>0.529</td>
<td>0.987</td>
</tr>
<tr>
<td>NQ (36.8%)</td>
<td>Previous 86 batches</td>
<td>37.772</td>
<td>1.145</td>
<td>0.390</td>
</tr>
<tr>
<td></td>
<td>Optimized Process (8 batches)</td>
<td>37.000</td>
<td>0.504</td>
<td>1.030</td>
</tr>
<tr>
<td>NTO (19.7%)</td>
<td>Previous 86 batches</td>
<td>19.249</td>
<td>0.648</td>
<td>0.875</td>
</tr>
<tr>
<td></td>
<td>Optimized Process (8 batches)</td>
<td>19.962</td>
<td>0.472</td>
<td>1.307</td>
</tr>
</tbody>
</table>
Optimized IMX-101 Manufacturing Process (3)

- **Observations**
  - Reduced kettle turn-over time did not compromise processability
    - Consistent efflux viscosity / flake homogeneity
  - Reduction in final mixing time did not result in settling
    - Consistent composition throughout casting operation
  - No change in IMX-101 flake appearance

- **First Article Testing**
  - 8 batches of IMX-101 manufactured, 5 consecutive subjected to FAT
  - All test requirements were met
  - Expanded Large Scale Gap Test:
    - 50% gap = 146 cards (62.5 kbar)
    - Comparable to baseline result

- **Final Verdict**
  - The optimized process was accepted

### Batch Data

<table>
<thead>
<tr>
<th>Batch</th>
<th>BAM Friction (N)</th>
<th>Naval Impact (cm)</th>
<th>VTS ml/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMX101-127</td>
<td>250.0</td>
<td>167.88</td>
<td>0.1</td>
</tr>
<tr>
<td>IMX101-128</td>
<td>265.2</td>
<td>164.82</td>
<td>0.03</td>
</tr>
<tr>
<td>IMX101-129</td>
<td>274.8</td>
<td>167.88</td>
<td>0.08</td>
</tr>
<tr>
<td>IMX101-130</td>
<td>279.6</td>
<td>171.00</td>
<td>0.11</td>
</tr>
<tr>
<td>IMX101-131</td>
<td>265.2</td>
<td>171.00</td>
<td>0.06</td>
</tr>
<tr>
<td>RDX Class 5 Std</td>
<td>162.9</td>
<td>21.13</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Spec Limit:
- > RDX Class 5
- < 150 cm
- < 2ml/g
Modernized Melt-Cast Explosive Manufacturing Facility

- Current Melt-Cast Facility (Bldg. L-4) at HSAAP will not meet future requirements of IM explosives
  - IMX-101, IMX-104, PAX-48, PAX-21, PAX-41
- IMX-101 optimized process will improve the current process efficiency at L-4
- Modernization of the Melt-Cast Facility will satisfy future production requirements
  - New design & technologies featured to further improve process efficiency
- Funded by the US Army Project Director Joint Services (PD-JS)
- Construction started: May 2011
- Scheduled completion date: Oct 2012
Modernized Melt-Cast Explosive Manufacturing Facility

Benefits / Improvements

- Annual production capacity increase > 250%
  - DNAN Pre-melter concept to streamline process
  - Growth opportunity with other IM products
- Replacing aging equipment with state-of-the-art systems
  - New flaker belt design eliminates water exposure
  - New discharge valve with better flow control
- Better control of temperature profile in melt kettle
  - Improve process and product consistency
- Accurate material balance resulting in consistent product composition
  - Load cell in kettle to ensure accurate ingredient increment
Modernized Melt-Cast Explosive Manufacturing Facility

- DNAN Pre-melter
  - Currently, DNAN melting and moisture removal takes almost 2 hours in the incorporation kettle
    - The optimized process did not address the reduction in DNAN melting time
  - Similar to the Comp B process (TNT melter), use of alternate vessel for DNAN melting and moisture removal will free up the incorporation kettle

![DNAN Pre-Melter](image)
Modernized Melt-Cast Explosive Manufacturing Facility

• Building Layout
Modernized Melt-Cast Explosive Manufacturing Facility

- Equipment Layout
Modernized Melt-Cast Explosive Manufacturing Facility

- Ingredient Incorporation

- Product Casting
Concluding Remarks

• Robust large scale manufacturing process for IMX-101
• Urgent need for process optimization due to higher demands
• 30% reduction in Kettle Turn-Over Time achieved (reduced unit cost)
• Improved process efficiency (six 1200 lb. batches per day currently)
• No significant difference observed from analytical results (all batches passed all spec requirements)
• More consistent composition results with the use of the DNAN level checker
• Modernized Melt-Cast Explosive Manufacturing Facility shall further enhance HSAAP capability and capacity as the center of excellence in IM explosive manufacturing
  • Improved product quality
  • Improved process efficiency
Acknowledgement

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  - Plant operators from Building L-4 at HSAAP