Meltable Explosives for Pressed Applications

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NDIA IM/EM Las Vegas, NV
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Overview

• Objectives
• Program Description
• Technology Description and Feasibility
• Characterization of Top Candidates
• Detonation Testing
• Final IM Testing
• Plan Forward
• Summary
Objectives

➢ To develop an explosive replacement for PBXN-9 in the Excalibur M982 155mm Warhead.
  • Utilizing a melt-cast explosive in a pressable form
  • Not intended as a PBXN-9 system-wide replacement
  • Specific to the M982 with transition potential to systems and applications with similar performance requirements.

➢ Demonstrate explosive replacement in tactical SCO, BI and FI IM Tests.
Program Description

- M982 contains a PBXN-9 HE fill
- Fuze protrudes into HE, with a PBXN-9 booster
  - Current booster must initiate the replacement HE fill
  - No detonation train/booster redesign intended

- Current HE is press-loaded, Beer-can shape at the aft end.
  - Replacement HE can be pressable or castable.

![Diagram of M982 with PBXN-9 HE fill and booster with WHD and PBXN-9 labels]
Technology Description

- PBXN-9 is a Sensitive Molding Powder
  - High Nitramines
  - Pressed Explosive

- Strategy is to develop a Melt Cast Alternative that will be flaked/granulated for pressing applications
  - Utilize NTIB ingredients
  - Meltable explosive geared towards improved cook-off reactions
  - Expecting reduction in performance as compared to PBXN-9
  - M982 requirements have trade space to accommodating explosives at Comp B energy levels
Explosive Development

- Thermo-chemical calculations were performed on over 40 formulations
- 9 formulations were selected for characterization
  - 5 focused on higher nitramine content to minimize the performance drop-off from PBXN-9
  - Tri-modal mixtures of HMX → Needed for a pourable cast
  - Other formulations tailored with HMX and DNAN targeting improved cook-off response
  - Several formulations leveraged from explosive replacement programs with a similar technical approach
### Explosive Development

<table>
<thead>
<tr>
<th>Name</th>
<th>Energetics</th>
<th>Non-Energetic Binder</th>
<th>Al</th>
<th>Density (g/cc)</th>
<th>Gurney (cal/g)</th>
<th>% N9</th>
<th>Det Velocity (km/s)</th>
<th>% N9</th>
<th>Pressure (Gpa)</th>
<th>% N9</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBXN-9</td>
<td>HMX</td>
<td>DOA/Hitemp</td>
<td>No</td>
<td>3.04</td>
<td>8.55</td>
<td>29.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X1</td>
<td>DNAN/HMX</td>
<td>Wax/DOA</td>
<td>No</td>
<td>1.68</td>
<td>2.84</td>
<td>93%</td>
<td>7.93</td>
<td>93%</td>
<td>26.2</td>
<td>89%</td>
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<tr>
<td>X2</td>
<td>DNAN/HMX</td>
<td>Wax/DOA</td>
<td>Yes</td>
<td>1.72</td>
<td>2.93</td>
<td>96%</td>
<td>7.83</td>
<td>92%</td>
<td>25.5</td>
<td>86%</td>
</tr>
<tr>
<td>X3</td>
<td>TNT/HMX</td>
<td>Wax/DOA</td>
<td>No</td>
<td>1.72</td>
<td>2.80</td>
<td>92%</td>
<td>7.90</td>
<td>92%</td>
<td>25.6</td>
<td>87%</td>
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<td>X4</td>
<td>TNT/HMX</td>
<td>Wax/DOA</td>
<td>No</td>
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<td>2.94</td>
<td>96%</td>
<td>8.08</td>
<td>94%</td>
<td>25.7</td>
<td>87%</td>
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<tr>
<td>X5</td>
<td>DNAN/HMX</td>
<td>None</td>
<td>No</td>
<td>1.75</td>
<td>2.83</td>
<td>93%</td>
<td>8.04</td>
<td>94%</td>
<td>26.4</td>
<td>89%</td>
</tr>
<tr>
<td>X6</td>
<td>DNAN/HMX</td>
<td>None</td>
<td>No</td>
<td>1.71</td>
<td>2.80</td>
<td>92%</td>
<td>7.87</td>
<td>92%</td>
<td>24.9</td>
<td>84%</td>
</tr>
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<td>X7</td>
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<td>Wax/DOA</td>
<td>No</td>
<td>1.66</td>
<td>2.80</td>
<td>92%</td>
<td>7.81</td>
<td>91%</td>
<td>25.0</td>
<td>85%</td>
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<td>X8</td>
<td>DNAN/RDX</td>
<td>None</td>
<td>No</td>
<td>1.76</td>
<td>2.69</td>
<td>88%</td>
<td>7.80</td>
<td>91%</td>
<td>24.6</td>
<td>83%</td>
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<tr>
<td>X9</td>
<td>TNT/HMX</td>
<td>Wax</td>
<td>Yes</td>
<td>1.83</td>
<td>2.92</td>
<td>96%</td>
<td>7.73</td>
<td>90%</td>
<td>27.5</td>
<td>93%</td>
</tr>
<tr>
<td>X10</td>
<td>TNT/RDX</td>
<td>Wax</td>
<td>Yes</td>
<td>1.80</td>
<td>2.93</td>
<td>96%</td>
<td>7.70</td>
<td>90%</td>
<td>26.7</td>
<td>90%</td>
</tr>
</tbody>
</table>

- X2 and X5 were too viscous due to the level of nitramines, even using tri-modal mixtures of HMX
- All candidates with DOA migrated in excess, and as the explosive billet is not 100% confined they were eliminated
Explosive Development

- X6, X8, X9 and X10 were characterized for performance and sensitivity:
  - Detonation Velocity
  - Large Scale Gap Test
  - Cylinder Expansion

- X8 was selected for further evaluation
  - X8 is the most mature, does not contain aluminum

<table>
<thead>
<tr>
<th>Name</th>
<th>TMD (%)</th>
<th>Density (g/cc)</th>
<th>Det Energy Cal/g</th>
<th>Det Velocity (km/s)</th>
<th>Pressure (kbar)</th>
<th>LSGT</th>
<th>Gurney</th>
<th>DV</th>
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<tbody>
<tr>
<td>PBXN-9</td>
<td>98</td>
<td>1.72</td>
<td>3.04</td>
<td>8.55</td>
<td>295</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X6</td>
<td>98</td>
<td>1.71</td>
<td>2.80</td>
<td>7.87</td>
<td>249</td>
<td>181</td>
<td>2.54</td>
<td>7.54</td>
</tr>
<tr>
<td>X8</td>
<td>98</td>
<td>1.74</td>
<td>2.68</td>
<td>7.73</td>
<td>240</td>
<td>154</td>
<td>2.44</td>
<td>7.33</td>
</tr>
<tr>
<td>X9</td>
<td>98</td>
<td>1.83</td>
<td>2.92</td>
<td>7.73</td>
<td>275</td>
<td>170</td>
<td>2.59</td>
<td>7.58</td>
</tr>
<tr>
<td>X10</td>
<td>98</td>
<td>1.80</td>
<td>2.93</td>
<td>7.70</td>
<td>267</td>
<td>166</td>
<td>2.59</td>
<td>7.47</td>
</tr>
</tbody>
</table>

- X8 was selected for further evaluation
  - X8 is the most mature, does not contain aluminum
Final Testing

- Prior to IM testing, detonation tests were performed to ensure the detonation train initiated X8
  - Simulated bodies
  - Identical booster
  - Simulated booster cup and fuze well

- Provides a large scale comparison to PBXN-9

- Done at hot and cold temperatures to identify potential initiation issues at extreme conditions
Hot Tests

N9

X8
Cold Tests

N9

X8
Cold Tests

- Probes 1 and 3 were located 15’ from the test item, at a 45° angle from the test item.
- Probes 2 and 4 were staggered 7’ behind probes 1 and 3, 22’ from the test item.

<table>
<thead>
<tr>
<th>Explosive</th>
<th>Condition</th>
<th>Probe 1 (psi - 15ft)</th>
<th>Probe 2 (psi - 22ft)</th>
<th>Probe 3 (psi - 15ft)</th>
<th>Probe 4 (psi - 22ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-4</td>
<td>Ambient</td>
<td>7.8</td>
<td>4.3</td>
<td>7.8</td>
<td>4.4</td>
</tr>
<tr>
<td>PBXN-9</td>
<td>Cold</td>
<td>22.5</td>
<td>6.0</td>
<td>21.7</td>
<td>6.9</td>
</tr>
<tr>
<td>X8</td>
<td>Cold</td>
<td>12.4</td>
<td>7.2</td>
<td>12.15</td>
<td>8.05</td>
</tr>
<tr>
<td>PBXN-9</td>
<td>Hot</td>
<td>17.6</td>
<td>6.6</td>
<td>14.2</td>
<td>9.7</td>
</tr>
<tr>
<td>X8</td>
<td>Hot</td>
<td>16.95</td>
<td>6.25</td>
<td>14.15</td>
<td>7.95</td>
</tr>
</tbody>
</table>
Final Testing

- X8 initiated high order at both Hot and Cold extremes
  - At Hot conditions, it compared favorably to PBXN-9
  - At Cold temperatures, PBXN-9 outperformed
  - Dents and fragment patterns of X8 looked very promising

- X8 was pushed forward for IM Testing
  - SCO at 6F/hr
  - BI with a triple burst
  - FI at 8300 ft/s

- PBXN-9 baseline testing
  - FI a Type (I) → Detonation
  - SCO a Type (II) → Partial Detonation
Slow Cook-off Testing Overview

- **Test: SCO per STANAG 4382**
  - 6F per hour
  - Thermocouples: Three (3) surface, Six (6) air
  - Measurements per 30 seconds

- **Configuration: Tactical**
  - Horizontal
  - No container was used, previous test results showed same reaction in or out of the container

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Distribution Statement A: Approved for public release; distribution is unlimited
Type II Reaction (Partial Detonation)
Bullet Impact Testing
Overview

Test: Bullet Impact per STANAG 4241

✓ Triple burst 0.50 cal AP bullets
✓ 850 m/s +/- 20 m/s
✓ 600 +/- 50 rounds/min
✓ Aim Points: Aim at main fill & aim at booster

Configuration: Tactical

✓ No container; not restrained to test stand; vertical; base down
✓ Worst case scenario when round is being set prior to firing

Distribution Statement A: Approved for public release; distribution is unlimited
X8: BI Test at Main Fill

Type V Reaction (Burning)
X8 BI Test at Booster

Type IV Reaction (Deflagration)

Bullet fired straight through booster

06/15/2011 11:50 AM

06/16/2011 08:12 AM

Distribution Statement A: Approved for public release; distribution is unlimited
Type IV Reaction (Deflagration)
Fragment Impact Testing Overview

- **Test:** FI per STANAG 4439
  - Mild-carbon steel conical fragment, 15.556 x 14.3mm at 18.6g
  - 2,530 +/- 90 m/s (8,300 +/- 300 ft/s)

- **Configuration:** Tactical
  - No container; not restrained; vertical; base down
  - Worst case scenario when round is being set prior to firing
X8 FI Test at Booster

Type V Reaction (Burning)

Fragment fired straight through booster
Type V Reaction (Burning)
X8 illustrated IM improvements over PBXN-9 in the warhead to penetrating threats.

<table>
<thead>
<tr>
<th>SCO</th>
<th>Bullet Impact</th>
<th>Fragment Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Booster</td>
<td>Main Fill</td>
</tr>
<tr>
<td>PBXN-9</td>
<td>(II)</td>
<td>Not Tested</td>
</tr>
<tr>
<td>X8</td>
<td>II</td>
<td>IV</td>
</tr>
</tbody>
</table>
Slow cook-off testing is not indicative of what may happen at the system level with venting solutions.

Scaled Thermal Explosive Experiments (STEX) were conducted to further examine the cook-off result.

- Test identifies the vent area required to produce a mild reaction to thermal threats
- Performed with PBXN-9 and X8
- Vent area available on M982 is ~2.5 in²

Vent area required to produce a mild burning reaction:

- PBXN-9 = 6.5 in²
- X8 = 0.53 in²
To press the melt-cast explosive, explosive flakes are ground to produce granules. The granules are then pressed for billet preparation.

- There was some concern that the physical grinding was separating ingredients.
- Batch of the granulated material was sieved to 4 size groups for composition analysis to ensure the integrity of the explosive is maintained.

<table>
<thead>
<tr>
<th>ID</th>
<th>Size (mm)</th>
<th>Ingredient 1</th>
<th>Ingredient 2</th>
<th>Ingredient 3</th>
<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;6 mesh</td>
<td>&gt; 3.36</td>
<td>+0.6</td>
<td>-0.7</td>
<td>-0.1</td>
<td>99.88</td>
</tr>
<tr>
<td>6-10 mesh</td>
<td>2.0 – 3.36</td>
<td>+0.6</td>
<td>-0.7</td>
<td>-0.4</td>
<td>99.67</td>
</tr>
<tr>
<td>10-20 mesh</td>
<td>0.84 – 2.0</td>
<td>+0.1</td>
<td>-0.4</td>
<td>-0.4</td>
<td>99.75</td>
</tr>
<tr>
<td>20-40 mesh</td>
<td>0.4 – 0.84</td>
<td>-2.4</td>
<td>+0.6</td>
<td>+1.5</td>
<td>99.76</td>
</tr>
</tbody>
</table>
Trends/Conclusions

➢ As granules are meltable, thermal improvements over traditional pressed explosives can be expected
  • STEX Test Results

➢ Shock sensitivity increases with granules
  ➢ Increase of ~30cards observed

➢ Granules have the ability to corner-turn

➢ Critical diameter decreases
  ➢ Increases applications technology can be associated with: small caliber systems, boosters

➢ Compositional integrity over majority of the PS distribution
Path Forward

Looking at alternate methods for producing granules of melt-cast flakes

• Physical Grinding
• Slurry Coating
• Prilling
• Shock Gel Technology
• Rotoformer Pastillation
Questions