Processing Studies of DNAN Based Melt-Pour Explosive Formulations

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Introduction and Background

- Until recently, Insensitive High Explosive (IHE) formulations used in Insensitive Munitions (IM) were mainly cast-cured or pressed formulations.
- New developments in melt-poured IHE and work that showed that they could also have good IM properties revived the interest for the type of explosive processing.
- GD-OTS Canada (formerly SNC TEC) has more than 60 years experience with TNT-based formulations, as well as some experience with PAX-21, PAX-25 and PAX-34 DNAN-based formulations.
- The objective of this presentation is to present the tests performed on two dinitroanisole (DNAN) based formulations (OSX-7 and OSX-8) as well as the results obtained.
Formulations Tested

- OSX-7: DNAN, NTO, RDX
- OSX-8: DNAN, NTO, HMX

- Reference formulations:
  - Composition B: 59.5% RDX, 39.5% TNT, 1.0% wax
  - PAX-34: DNAN, NTO, TATB, HMX

- Components:
  - DNAN: Dinitroanisole
  - NTO: 3-nitro-1,2,3-triazol-5-one
  - HMX: Octogen
  - RDX: Hexogen
  - TATB: 1,3,5-triamino-2,4,6-trinitro benzene
Viscosity and Sedimentation Testing

- Viscosity and particle size distribution of the solids are important characteristics for melt-pour formulations.
- A high viscosity can impair mixing and pumping operations and can lead to more air entrapment during loading.
- A low viscosity can also affect air entrapment and enhances solid particles settling in the equipment and in the loaded shell bodies.
- GD-OTS Canada series of characterization tests are used to evaluate the formulation viscosity and the tendency of its solid particles to settle.
Viscosity and Sedimentation Testing

- The test is performed using a double jacket heated pot containing 1.5 kg of material with a Brookfield viscometer equipped with a “A” T-shaped spindle rotating at 20 RPM.
- Viscosity measurements taken after 0, 7.5 and 15 minutes.

- In between measurements, the material is allowed to settle freely, without being agitated.
- The test temperature is maintained throughout the test duration.
## Viscosity and Sedimentation Testing

- **Viscosities measurements**

<table>
<thead>
<tr>
<th>Formulations</th>
<th>OSX-7</th>
<th>OSX-8</th>
<th>PAX-34</th>
<th>Comp B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test temperature</td>
<td>98°C (208°F)</td>
<td>98°C (208°F)</td>
<td>98°C (208°F)</td>
<td>93°C (199°F)</td>
</tr>
<tr>
<td>Initial viscosity (cP)</td>
<td>3040</td>
<td>1440</td>
<td>880</td>
<td>700-1000</td>
</tr>
<tr>
<td>Viscosity after 7.5 minutes (cP)</td>
<td>3286</td>
<td>1520</td>
<td>1040</td>
<td>1000-1400</td>
</tr>
<tr>
<td>Viscosity after 15 minutes (cP)</td>
<td>3440</td>
<td>1680</td>
<td>2720</td>
<td>2000-2400</td>
</tr>
</tbody>
</table>
Viscosity and Sedimentation Testing

- The viscosity test is immediately followed by the sedimentation test.
- The material in the heated test pot from the viscosity test is poured onto a pan and observations are made on:
  - The way the material flows
  - The amount of material remaining in the test pot
  - The way the material places itself on the pan
- OSX-7: appears homogeneous and flows steadily.
- OSX-8: Visual segregation of constituents visible during pouring. It is very liquid at first and more viscous towards the end.
Viscosity and Sedimentation Testing

OSX-7

OSX-7

OSX-8

OSX-8
Thermal Characterization

- With melt-poured formulations, controlled solidification is required to prevent formation of defects in the cast.
- The thermal behaviour is studied using a split mould cylinder loaded with the formulation. The temperature profile is recorded and material shrinkage is observed.
Thermal Characterization

- OSX-7 – Center Thermocouples

- OSX-7 #1
- OSX-7 #3
- OSX-7 #5
- OSX-7 #7
- OSX-7 #9
- CompB #1
- CompB #3
- CompB #5
- CompB #7
- CompB #9
Thermal Characterization

- OSX-8 – Center Thermocouples

![Thermal Characterization Graph](image-url)
Thermal Characterization

- OSX-7 and OSX-8 cool and solidify much faster than Composition B.
- The charges were removed from the split-mould cylinder and sectioned along their longitudinal axis.
  - Both OSX-7 and OSX-8 shrink less than Composition B. The charge had a large cavity with a diameter of \( \approx 35 \) mm and other small cavities below the central cavity.
Sedimentation studies

- Relative percentages of components from samples taken in the thermal characterization cylinder compared to the initial values in the composition.
  - OSX-7 is more viscous leading to less variations
  - Ingredients variations are small compared to composition B

<table>
<thead>
<tr>
<th>Position in the cylinder</th>
<th>OSX-7 Relative weight percentage</th>
<th>OSX-8 Relative weight percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom -1</td>
<td>NTO 0.95 HMX 1.105</td>
<td>NTO 1.03 HMX 1.105</td>
</tr>
<tr>
<td>2</td>
<td>NTO 1.00 HMX 1.00</td>
<td>NTO 0.97 HMX 1.02</td>
</tr>
<tr>
<td>3</td>
<td>NTO 1.05 HMX 1.05</td>
<td>NTO 0.99 HMX 1.05</td>
</tr>
<tr>
<td>4</td>
<td>NTO 1.00 HMX 1.00</td>
<td>NTO 0.98 HMX 1.02</td>
</tr>
<tr>
<td>5</td>
<td>NTO 0.95 HMX 1.105</td>
<td>NTO 0.97 HMX 1.105</td>
</tr>
<tr>
<td>6</td>
<td>NTO 1.00 HMX 1.00</td>
<td>NTO 0.98 HMX 1.02</td>
</tr>
<tr>
<td>7</td>
<td>NTO 1.05 HMX 1.05</td>
<td>NTO 0.99 HMX 1.05</td>
</tr>
<tr>
<td>Top -8</td>
<td>NTO 1.10 HMX 0.97</td>
<td>NTO 1.03 HMX 1.02</td>
</tr>
</tbody>
</table>

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Shell Body Loading

- 105 mm HE M1 shells were loaded using standard process conditions, but at a higher loading temperature for OSX-7 and OSX-8.

- A shell body instrumented with 6 thermocouples (located at 1.2, 3.7, 5.7, 7.7, 9.2 and 11.2 in from base) was included to record the cooling temperature profile.

- Radiographic inspection was performed on the loaded shell bodies.
Shell Body Loading

- OSX-7: Formulation solidifies much faster than composition B (60 minutes faster).
## Shell Body Loading

- **OSX-7: Filling results**
  - Good filling quality free of major casting defects with only minimal adjustments of composition B parameters and no change to the equipment.
  - Strong wall adherence in the bottom section.
  - Minimal acceptable cavities to be solved in future DOE studies.
OSX-8: Formulation solidifies much faster than composition B and similar to OSX-7 (60 minutes faster)
Shell Body Loading

- OSX-8: Filling results
  - Good filling quality free of major casting defects with only minimal adjustments of composition B parameters and no change to the equipment.
  - Strong wall adherence in the bottom section.
## Mechanical properties in compression

<table>
<thead>
<tr>
<th>Property</th>
<th>OSX-7</th>
<th>OSX-8</th>
<th>Comp B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum stress ($S_m$) [MPa]</td>
<td>18.9 ± 1.6</td>
<td>17.8 ± 1.3</td>
<td>8.1 ± 1.8</td>
</tr>
<tr>
<td>Strain at maximum stress ($e_m$) [%]</td>
<td>2.5 ± 0.3</td>
<td>2.5 ± 0.1</td>
<td>2.0 ± 0.3</td>
</tr>
<tr>
<td>Young's modulus (M) [MPa]</td>
<td>1708 ± 281</td>
<td>1436 ± 236</td>
<td>840 ± 147</td>
</tr>
<tr>
<td>Stress at rupture ($S_R$) [MPa]</td>
<td>9.5 ± 0.8</td>
<td>8.9 ± 0.7</td>
<td>4.0 ± 0.9</td>
</tr>
<tr>
<td>Strain at rupture ($e_R$) [%]</td>
<td>3.5 ± 0.4</td>
<td>3.3 ± 0.2</td>
<td>2.7 ± 0.1</td>
</tr>
</tbody>
</table>
Variable Confinement Cook-off Test

- VCCT equipment

![Diagram Description]

- Thermocouple in air
- Confine ment tube
- Steel washer
- Thermocouples
- Heating band
- Aluminum tube

![Image of VCCT equipment]
# Variable confinement cook-off tests

## Results

<table>
<thead>
<tr>
<th>Composition</th>
<th>0.39mm (0.0155&quot;) confinement</th>
<th>1.19mm (0.045&quot;) confinement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reaction T°</td>
<td>Reaction type</td>
</tr>
<tr>
<td>OSX-7</td>
<td>182°C (360°F)</td>
<td>V</td>
</tr>
<tr>
<td>OSX-8</td>
<td>199°C (390°F)</td>
<td>V</td>
</tr>
<tr>
<td>Composition B</td>
<td>184°C (363°F)</td>
<td>III</td>
</tr>
</tbody>
</table>
Summary and Future work

- Two IM DNAN based melt-pour formulations (OSX-7 and OSX-8) were studied in GD-OTS Canada pilot plant equipment and characterized.

- Both OSX-7 and OSX-8 exhibit higher melting point, higher viscosity and faster crystallization but the actual GD-OTS Canada modified Meissner process can be used without modification to the equipment and minor adjustments to the parameters to fill projectiles as shown in studies on 105mm M1 filling.

- Both OSX-7 and OSX-8 settle less than typical composition B.

- Both formulations present mechanical properties in compression about twice as good as composition B.

- Variable confinement Cook-off Tests indicate that OSX-7 and OSX-8 better withstand cook-off tests (burning vs explosion for the confinement tested)

- Future work planned: Additional characterization studies: detonation properties, physical properties during ageing, LSGT, filling of other projectiles, IM tests.