Underwater Performance Demonstrations and IM Responses of Two Insensitive Explosives

IMEMTS 2012, Las Vegas

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Background

- FPX V40 explosive has shown extremely good detonation characteristics in DFC application having remarkably better performance than competing products
- Underwater performance parameters were measured since FPX V40 is also explosive fill in BOXER underwater mine disposal charge
- TNT and FOXIT were used as reference explosives since TNT is extensively tested in various applications and FOXIT is proved to be effective but extremely insensitive underwater explosive
**Underwater measurements**

**Test setup**
- Water surface
- Pressure sensors
- Charge

**Measured parameters**
- Maximum pressures, $P_{\text{max}}$
- Time, $s$

**Calculated parameters**
- Time constants, $\theta$
- Shock Impulses, $I_{\text{shock}}$
- Shock energies, $E_{\text{shock}}$

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**Test setup**

- Water surface
- Pressure sensors
- Charge

- $0.1 \text{ kg}^{1/3}\text{m} < R_{\text{red}} < 0.36 \text{ kg}^{1/3}\text{m}$

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**Measured parameters**

- Maximum pressures, $P_{\text{max}}$
- Time, $s$

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**Calculated parameters**

- Time constants, $\theta$
- Shock Impulses, $I_{\text{shock}}$
- Shock energies, $E_{\text{shock}}$
Detonation parameters of the studied explosives

- Detonation velocities and pressures
  - TNT: 6900 m/s ; 18 GPa
  - FPX V40: 6600 m/s ; 17 GPa
  - FOXIT: 5500 m/s ; 11 GPa

- Detonation energies according to modified Kistiakowsky-Wilson rule
  - TNT: Q = 4250 kJ/kg
  - FPX V40: Q = 7280 kJ/kg (H-6: Q = 7270 kJ/kg)
  - FOXIT: Q = 8030 kJ/kg (HBX-3: Q = 8930 kJ/kg)
  - TNT / Al (60/40): Q = 8470 kJ/kg (HBX-3: Q = 328 kJ/kg)

- Detonation power (Q x V)
  - TNT: Q x V = 315 kJl/kg^2
  - FPX V40: Q x V = 435 kJl/kg^2 (H-6: Q = 416 kJl/kg^2)
  - FOXIT: Q x V = 413 kJl/kg^2 (HBX-3: Q = 328 kJl/kg^2)
  - TNT / Al (60/40): Q x V = 201 kJl/kg^2
Maximum pressures

- Pressure decrease

\[ P = P_{\text{max}} e^{-\frac{t}{\theta}} \]

- Time constant, \( \theta \) is the slope of the initial linear part in the logarithmic graph

- \( P_{\text{max}} \) is calculated from the equation of this initial linear part of the exponential curve
Maximum pressures

<table>
<thead>
<tr>
<th>V40</th>
<th>FOXIT</th>
<th>TNT</th>
</tr>
</thead>
<tbody>
<tr>
<td>R_{red}</td>
<td>P_{max}</td>
<td>R_{red}</td>
</tr>
<tr>
<td>0,356</td>
<td>18,2</td>
<td>0,359</td>
</tr>
<tr>
<td>0,267</td>
<td>11,6</td>
<td>0,245</td>
</tr>
<tr>
<td>0,178</td>
<td>7,3</td>
<td>0,179</td>
</tr>
<tr>
<td>0,133</td>
<td>4,5</td>
<td>0,135</td>
</tr>
<tr>
<td>0,107</td>
<td>3,5</td>
<td>0,108</td>
</tr>
</tbody>
</table>

- Despite lower P_{CJ} values, FPX V40 and FOXIT showed higher maximum pressures than TNT
- Results are consistent with literature values

In addition to gentle slope of the pressure drop as a function of time, in aluminized compositions, max pressure seems to remain higher also as a function of distance.
Maximum pressures
- Experimental vs. Literature

Good correlation with explosives having similar Al content and Q-values.


**Shock impulses**

- FPX V40 and FOXIT showed much higher $I_{\text{shock}}$ values than TNT
- FOXIT has even higher $I_{\text{shock}}$ than FPX V40

\[
I_{\text{Shock}} = \int_{0}^{5\theta} Pdt
\]

**FOXIT showed the highest $I_{\text{Shock}}$ values**
- Lower $P_{\text{max}}$
- Low gradient of pressure drop
- Pressure remains higher for longer time

Higher Al content and Q value
Shock impulses – Experimental vs. Literature

At shorter distances FPX V40 and FOXIT have higher $I_{\text{shock}}$ values than H-6 or HBX-1

Because of higher oxygen content?

TNT results correlate quite well with literature values
**Shock energy**

- FPX V40 has the highest $E_{\text{shock}}$ value, although $I_{\text{shock}}$ was lower than for FOXIT
  - Shock energy difference increased with decreasing distance to charge in favor of FPX V40
- Despite higher detonation values ($V_0D$, $P_{\text{CJ}}$), TNT showed lower $E_{\text{shock}}$ values at all measured distances
  - The $E_{\text{shock}}$ values were lower even if the shock compensation coefficient is taken into account
IM responses - FPX V40

- Unfortunately the IM testing of BOXER has been delayed, and although the testing has begun, no results are available at this point.
- FPX V40 has been extensively tested in Forcit’s DFC, where IM properties have been verified as follows

<table>
<thead>
<tr>
<th>Test</th>
<th>Reaction level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bullet Impact</td>
<td>V, No reaction</td>
</tr>
<tr>
<td>Fast Heating</td>
<td>V, Burning</td>
</tr>
<tr>
<td>Slow Heating</td>
<td>V, Burning</td>
</tr>
<tr>
<td>Sympathetic Reaction</td>
<td>V-VI, Burning / Deflagration</td>
</tr>
<tr>
<td>Fragment Impact</td>
<td>V, Burning</td>
</tr>
<tr>
<td>Shaped Charge Jet</td>
<td>I-II, Detonation /Partial Detonation</td>
</tr>
</tbody>
</table>
Conclusions

• According to these results
  – FPX V40’s underwater performance is superior to TNT, H-6 and HBX-1/3
  – High pressure stage of shock lasts longer increasing the shock impulse
  – Shock energy is higher than FOXIT’s especially with short distances from the charge

• IM test results show that insensitiveness does not compromise high energy content or detonation performance
Thank You for Your Attention

From the song
The Blackest Ace

Fortuna balls
Lips of eager women
Lady Luck thanks the brave man
Carves a notch on the headboard

Life is the color of the missing card

I played away my homestead – ridgepole and all
The blackest ace, the mirror of soul
If I didn't win with these, I lost
Now the blackest ace is the mirror of soul

~ Viikate (= Scythe)
Orig. lyrics Kaarle Viikate
Engl. translation Marko Niskapohja