PROCESSABILITY OF CAST COMPOSITE EXPLOSIVES

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INTRODUCTION

- PBXs (Plastic Bonded eXplosives), are produced by different technologies: pressing, extrusion or casting.

- Cast PBX consist of nitroamine crystal explosive component and polymeric binder, but often they contain oxidizer and fuel component (metal powder).

- Cast cured explosives are loaded directly into a corresponding weapon immediately after preparation and, by controlled crosslinking at higher temperature, they turn into a solid explosive charge.
• After addition of curing agent, rheological behavior depends on a number of variables: time, temperature, filler concentration, chemical formulation, reaction kinetics etc, which makes rheological characterization very complex.

• The easiness of manufacturing PBX by casting technology is often defined as "processability", as a possibility to homogenise and cast a composite explosive formulation.

• Flow characteristics of uncured PBX are affected by the formulation and the conditions of production.

• There are several factors that have influence: characteristics of prepolymer, shape and particle size distribution, content of solid particles, packaging fractions, type and content of plasticizer, type and content of “bonding agent”, type of curing agent, type and content of curing cataliser, presence of impurities.
• "Pot life" - the time the mixture remains sufficiently fluid to permit processing and casting. It is often determined by measuring viscosity as a function of time after homogenization, at the temperature of the explosive manufacture.

• Viscosity of PBX should not be too high to obtain better dispersion of components, and not too low to avoid their sedimentation. Viscosity of cast composite explosives should change slowly during time, so the "pot life" is long enough.

• The time dependence of viscosity of uncured PBX is a nonlinear function, in the first 2-3 hours it is favorable that viscosity changes very slowly.
• For cast composite explosive it is important to achieve minimal porosity, because voids or gas cavities inside of an explosive charge could represent potential risk of the "hot-spot" initiation or ignition sites.

• In this research different cast PBX compositions are examined, prepared with thermoreactive polymer binder (hydroxyl-terminated poly(butadiene) - HTPB), octogen as explosive component (HMX), ammonium perchlorate as oxidant component (AP), aluminium, magnesium and boron as metal fuel.

• Viscosity dependence on time was observed, but also density and porosity of explosive samples, as well as detonation velocities, as one of the most important parameters of effectiveness of an explosive
MATERIALS AND EXPERIMENTS

7 different explosive compositions were compared from the aspect of their processability, made of following raw materials:

- HMX (DINO, Norway, class A/C),
- Al (Alcan TOYO, average particle diameter ~ 5 μm),
- Mg (ECKA GRANULES – Austria, average particle diameter ~ 16 μm),
- B (average particle diameter ~ 5 μm),
- AP (average particle diameter ~ 7 μm),
- binder (HTPB, cured by isophoronediisocyanate, IPDI).
Labels of cast composite explosives and the content of the components are following:

- PBX-01: HMX/AP/Al/Mg/HTPB=45/10/27/3/15,
- PBX-02: HMX/AP/Al/Mg/HTPB=45/10/21/9/15,
- PBX-03: HMX/AP/Al/Mg/HTPB=31/20/27/3/19,
- PBX-04: HMX/AP/Al/Mg/HTPB=31/20/21/9/19,
- PBX-05: HMX/AP/Al/B/HTPB=40/10/20/10/20,
- PBX-06: HMX/AP/Al/Mg/B/HTPB=40/10/10/10/20,
- PBX-07: HMX/Al/Mg/B/HTPB=50/10/10/10/20.

Explosive samples:
- gray – with Mg and Al,
- dark brown - with B.
Main phases of PBX manufacture are:

- preparation of raw materials (drying, sieving, weighing),
- dosing and homogenization of the components,
- casting the composite mixture directly into casings or into molds,
- curing at high temperature,
- quality control of the explosive.

Drying of metal powders (Al and Mg) and explosive (HMX)
Technological parameters of preparing all compositions were the same:

- order of dosing components,
- stirring speed and
- time of homogenization,
- mixing time of composite mixture after adding curing agent

After homogenization, explosive is directly poured in previously prepared molds (diameter 50 mm, height 200 mm), and left in the oven to solidify at higher temperature.


**Explosive characterisation**

- **Compatibility** of the components was examined on heat flow calorimeter LKB Bioactivity Monitor 2277
- Samples of uncured HTPB polymer binder, magnesium, boron, and mixtures were heated for 456 hours at 75ºC (STANAG 4147, test 2).

\[ D = \frac{2M}{(E+S)} \]

- \( D \) – relative compatibility
- \( M \) – heat generation of the mixture, J/g
- \( E \) – heat generation of Mg or B, J/g
- \( S \) – heat generation of the polymer, J/g

For \( D < 2 \) the mixture is considered to be compatible, for \( D > 3 \) the mixture is considered to be incompatible and for \( 2 < D < 3 \) the mixture is considered "moderately" incompatible.
• Viscosities are measured during 75 minutes, at every 15 min, using the Brookfield's viscometer type HBT at 50 °C, with the measuring spindle T-C, rotation speed of 5 min⁻¹.
• **Densities** of the prepared explosives were determined according to standard method MIL 286C, measuring masses of the samples of the explosive charge on the Mohr’s scale in toluene at 25 °C. Experimentally obtained values were then compared to calculated theoretical density values

\[
1/\rho_t = W_A/\rho_A + W_B/\rho_B
\]

- \(\rho_t\) - theoretical value of density,
- \(W_A, W_B\) - mass fraction of the components,
- \(\rho_A, \rho_B\) – component’s density.

• **Porosities** were calculated according to

\[
\nu = (1 - \rho_e / \rho_t) \cdot 100 \%
\]

- \(\nu\) - porosity,
- \(\rho_e\) - experimental value of density.
• **Detonation velocity** was measured in the zone of stable detonation in the explosive charge using ionizing probes, oscilloscope and electronic counter Pendulum CNT-91.

**Pendulum CNT-91**
**Timer/Counter/Analyzer**
- with 2 channels for START and STOP probe,
  -- resolution 50 ps.

**Tektronix Digital Oscilloscope DPO4054**
- with 4 analogue channels,
- frequency 500 MHz.
Results and discussion

- Microcalorimetry compatibility test results are given as the release of heat, or heat flow curves for HTPB, B, Mg and mixtures thereof, as well as the calculated theoretical curves.

*Heat flow curves for examination of compatibility with Mg (a) and with B (b)*
Microcalorimetry compatibility test results

<table>
<thead>
<tr>
<th>Test</th>
<th>Sample</th>
<th>Energy released [J/g]</th>
<th>Relative compatibility, D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HTPB/Mg</td>
<td>13.16</td>
<td>2.53</td>
</tr>
<tr>
<td></td>
<td>Mg</td>
<td>10.17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HTPB</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>HTPB/B</td>
<td>11.67</td>
<td>1.37</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>13.083</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HTPB</td>
<td>3.9</td>
<td></td>
</tr>
</tbody>
</table>

- Polymeric binder is moderately incompatible with magnesium (2 < D < 3), and compatible with boron (D < 2).
- Mg accelerates polymerisation of HTPB and this phenomenon is known in literature.
- Although it has shown compatibility with HTPB in microcalorimetry, B has shown inadequate behavior during manufacture of explosive mixtures: huge increase in the viscosity of the mixture, until the consistency of a paste, appearance of viscous boron oxide and boric acid, which is indicated by the literature, stickyness of the explosive samples after hardening.
### Viscosities of cast PBX compositions in defined times

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Dynamic viscosity $\eta$ [Pa·s]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>15 min</td>
</tr>
<tr>
<td>PBX-01</td>
<td>156,4</td>
</tr>
<tr>
<td>PBX-02</td>
<td>288</td>
</tr>
<tr>
<td>PBX-03</td>
<td>82</td>
</tr>
<tr>
<td>PBX-04</td>
<td>124</td>
</tr>
<tr>
<td>PBX-05</td>
<td>&gt; 1000</td>
</tr>
<tr>
<td>PBX-06</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(could not be measured, mixture had a paste-like consistency, could not be cast)</td>
</tr>
</tbody>
</table>
**Diagrams** $\eta = f(t)$

- Mg causes a higher viscosity. PBX-02 and PBX-04 have higher viscosities than their couples regarding the content of other components (PBX-01 and PBX-03, respectively).

- The lowest viscosities are registered for compositions PBX-03 and PBX-04, having 19 wt.% of HTPB.

- PBX-05 – PBX-07 that contain boron have significantly higher viscosities that could not be measured with the same spindle on the used viscometer.
Densities, porosities and detonation velocities of examined PBX

<table>
<thead>
<tr>
<th>Explosive</th>
<th>$\rho_T$ [g/cm$^3$]</th>
<th>$\rho_e$ [g/cm$^3$]</th>
<th>$\nu$ [%]</th>
<th>D [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBX-01</td>
<td>1.773</td>
<td>1.753</td>
<td>1.11</td>
<td>6806</td>
</tr>
<tr>
<td>PBX-02</td>
<td>1.734</td>
<td>1.702</td>
<td>1.83</td>
<td>7154</td>
</tr>
<tr>
<td>PBX-03</td>
<td>1.709</td>
<td>1.697</td>
<td>0.68</td>
<td>6125</td>
</tr>
<tr>
<td>PBX-04</td>
<td>1.672</td>
<td>1.663</td>
<td>0.57</td>
<td>6059</td>
</tr>
<tr>
<td>PBX-05</td>
<td>1.631</td>
<td>1.420</td>
<td>13.0</td>
<td>5482</td>
</tr>
<tr>
<td>PBX-06</td>
<td>1.628</td>
<td>1.440</td>
<td>11.6</td>
<td>6060</td>
</tr>
<tr>
<td>PBX-07</td>
<td>1.645</td>
<td>1.580</td>
<td>4.0</td>
<td>6209</td>
</tr>
</tbody>
</table>
Conclusion

• Compatibility of components was tested by microcalorimetry, and it was observed that Mg is moderately incompatible with the binder, and that B is compatible. However, boron has shown undesired behavior in the explosive mixtures, causing a huge increase of the viscosity and making the mixture uncastable, because of the reactions of B with HTPB.

• Viscosity-time dependences, densities and porosities are determined for examined samples. For the samples with good casting possibilities, the greatest effect on rheological properties has mass concentration of binder, then the content of Mg, which increases the viscosity. The higher amount of Mg in compositions with the same content of other components causes higher values of viscosity, thus slightly reduced time of processing (castability) of these PBX. The examined compositions with boron had very high viscosity and did not have good flow characteristics.

• Measured densities of samples with Al and Mg have shown to be very close to theoretical values. Values of porosity are low for these compositions, especially for those having higher content of HTPB binder. Compositions with boron had very high porosities, which is not convenient for PBX. Detonation velocities are higher for PBX with higher densities, and lower for the PBX with high porosity, i.e. for compositions with B.

• Considering the obtained results, explosive compositions with aluminium and magnesium are good candidates for industrial production, while compositions with boron are not convenient for production by casting technology.
Thank you for the attention!