# Formulation of a melt castable general purpose insensitive high explosive

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A thermoplastic analog of PBXW-124/125 was formulated, characterized, scaled-up and tested for performance and insensitive high explosive characteristics in generic test units. The processing data indicated that the formulation should be compatible with steam-kettle processing equipment. During this research, the formulations were processed in Baker Perkins mixers, however, manufacturability was demonstrated in steam kettle equipment with an inert analog. The intermediate performance and sensitivity characteristics (Detonation Velocity, Card Gap etc.) generally showed a close correspondence with those of PBXW-124/125. The formulation which was scaled up and tested was designated TE-T 7005. With regards to large scale test results, however, comparable performance and excellent insensitivity (better than the standard PBX) was demonstrated.

## Introduction:

The overall purpose of this research project was to modify current US Navy (USN) Plastic Bonded Explosives (PBX) compositions such as PBXW-124 and PBXW-125 (which employ an HTPB/IPDI curable binder system) such that the curable binder is replaced with a proprietary thermoplastic binder known as TTB-531 [1),2)]. This would result in a significant cost reduction of these compositions due to the following reasons. First, employment of traditional TNT steam kettles is possible, thus eliminating the need to purchase expensive Baker-Perkins (BP) type equipment which are in limited availability at Government Owned (GO) facilities. TNT kettles are much less sophisticated than BP type equipment, much less expensive, and in high availability at GO facilities; therefore, loading operations could continue at GO plants. Secondly, because the binder is thermoplastic and solidifies upon cooling, the cure cycle required for traditional PBX is eliminated, further reducing production costs. Associated with this thermoplastic nature is an "infinite potlife" such that the explosive loading operation is not time limited by virtue of a cure type reaction. Thirdly, uncontaminated scrap can be remelted and reused, drastically reducing waste disposal costs, environmental concerns and permitting easy demilitarization. This research consisted primarily of two phases. The first phase consisted of a development and optimization effort which was designed to lead to selection of a candidate composition to scale-up in Phase-2. The second phase involved the loading of sixteen generic test units which were essentially steel tubes measuring ≈ 20 cm × 41 cm (8 in. × 16 in) for performance and Insensitive Munition (IM) testing [3),4)]. This paper covers Phase-1. Test results from Phase-2 will be reported in subsequent papers.

## Theory:

Hydroxyl Terminated Poly Butadiene (HTPB) was originally developed as a binder for solid rocket propellants and is therefore intended to burn rapidly. Early PBX development recognized that the physical properties of HTPB allowed improved stress/strain characteristics and in some instances decreased the sensitivity of certain explosives relative to TNT based explosives (i.e. PBX-109). However, Explosives

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Table 1 Composition of PBX formulations

| Ingredient | Vendor | Wt.% and Diameter(μ) (PBX-122) | Wt.% and Diameter(μ) (PBX-124) | Wt.% and Diameter(μ) (PBX-125) |
|---|---|---|---|---|
| HTPB+E702 | -- | 4.85+0.05 | 4.85+0.05 | 4.44+0.05 |
| IPDI+TPB | -- | 0.46+0.01 | 0.46+0.01 | 0.45+0.01 |
| IDP+Lecithin | -- | 7.23+0.4 | 7.23+0.4 | 6.65+0.4 |
| Al Powder | Reynolds Alcan | 15/5 | 20/18 | 26/18 |
| AP | Kerr McGee | 20/200 | 20/200 | 20/200 |
| NTO | Olin | 47/250 | 27/250 | 22/250 |
| RDX | Holston AAP | 5/4 | 20/4 | 20/4 |

such as PBX-124 contain both aluminum (Al(to enhance air blast)) and Ammonium Perchlorate (AP(to oxidize the aluminum and binder)) which are normal ingredients found in many Class 1.3 rocket propellants. Therefore, HTPB/Al/AP PBX compositions are quite sensitive to friction and under bullet/fragment impact conditions normally result in a deflagration reaction. The formulation information for PBX-122, PBX-124 and PBX-125 is found at Table 1. These PBX formulations are based upon the insensitive high explosive known as 3-Nitro-1,2,4-triazal-5-one (NTO).

Results:

A Thiokol Corp. proprietary thermoplastic binder was developed and identified as TTB-531 (Patent Pending) [5] which, when substituted for the HTPB binder system of PBX-122, resulted in a significant reduction in impact and friction sensitivity (Table 2). It was theorized that because of the very fluid nature of TTB-531, the individual solid particles, such as AP, were much better coated and, due to the thermoplastic nature of TTB-531, energy which would normally be used to ignite a PBX would first be required to melt the binder thus lowering the amount of energy that the solid particles were directly exposed to. At the upper limits of the testing apparatus for both friction and impact tests, the thermoplastic version of PBX-122 was unreactive while the PBX version exhibited an exothermic reaction.

TTB-531 has no elastomeric capability and therefore is quite brittle, similar to TNT. However, the melting point is very sharp (within a range of 2℃) and can be shifted either up or down by increasing the molecular weight of the polymer.

Table 2 Sensitivity reduction of PBXW-122 when HTPB is replaced with TTB-531

| Binder type→ | HTPB | TTB-531 |
|---|---|---|
| Test↓ | -- | |
| Friction | 160 N | > 260 N* |
| 5kg Impact | 76㎝ | > 320㎝* |

*Note: These values were the upper limits of the testing equipment.

After PBX-122 was subjected to air blast testing, it was determined that PBX-122 was under-oxidized and therefore, the replacement study should occur with a composition containing additional AP such as PBX-124 or PBX-125. Both compositions revealed higher air blast performance than PBX-122, however, as AP content increased, fragment velocity decreased. Therefore, a hybrid of PBX-124 and PBX-125 (which were undergoing development at the same time) was selected for the study as detailed in Table 3 and was designated DTS-13998.

Seven 1-gallon mixes of DTS-13998 were made for loading test samples for overall characterization of the baseline composition. Sensitivity, performance and physical properties of DTS-13998 are detailed in Table 4.

Discussion:

Expanded Large Scale Gap Testing (ELSGT) resulted in a bracketing of composition DTS-13998 between 52 kbars (negative) and 57 kbars (positive). The witness plate for the test at 52 kbars remained intact with no holes punched.

TAble 3 · Composition of baseline thermoplastic baseline formulation, DTS-13998

| Ingredient | Vendor | Lot No. and/or Type | Wt.% and Diameter( m) (DTS-13998) |
|---|---|---|---|
| TTB-531 | Thiokol | N/A | 12.0/N/A |
| Al Powder | Reynolds | S-400 | 23.0/5* |
| AP | Kerr McGee | 3017 | 20.0/200 |
| NTO | Olin | 0990 | 25.0/250 |
| RDX | Holston AAP | A 91031 | 20.0/4.3 |

*The only difference between DTS-13998 and DTS-14009 or TE-T 05 was the aluminum powder particle size was 17 m rather than 5 m.

Table 4 Sensitivity, performance and physical properties of DTS-13998

| Test | Result for DTS-13998 | Result for DTS-14009 |
|---|---|---|
| End of Mix Viscosity (Brookfield) | 1.4 kp@88℃ | 1.8 KP@96℃ |
| Impact (2.5kg, NSWC apparatus) | 99cm | 148cm |
| Friction (NSWC Pendulum) | 108 N | 112 N |
| ESD | > 45 J | > 45 J |
| First DSC Exotherm | 198℃ | 198℃ |
| #8 Cap Test | No Reaction | Not tested |
| Vacuum Thermal Stability | 0.815 cc/g@100℃ | 0.276 cc/g@100℃ |
| Self Heating | 98.6℃ | 83.9℃ |
| NOL Card Gap | +@65 kbars/−@64 kbars (+@79 cards/−@80 cards) | +@63.5 kbars(−@63 kbars) |
| ELS Card Gap | +@57 kbars/−@52 kbars) | +@52.5 kbars/−@48 kbars) |
| Detonation Velocity | 6195 m/sec@8.9cm Confined | 6434 m/sec@8.9cm Confined |
| Critical Diameter | 6.35cm Unconfined | 5.08cm Unconfined |
| Density | 1.794 g/cm³ | 1.7947 g/cm³ |
| Coefficient of Thermal Expansionw (CTE) | $4.582 \times 10^{-5}$ inch/inch ℉ (−10 to 100 ℉) $10.226 \times 10^{-5}$ inch/inch ℉ (100 to 154 ℉) | Not tested |
| Thermal Shrinkage | 0.614%(88℃ to 21℃); 0.00916%/℃ | 0.6%(88℃ to 21℃); 0.009%/℃ |
| Ignition and Unconfined Burning | Burn Only | Not Tested |

An 8.9cm × 35.6cm(3.5" × 14") cylinder of DTS-13998 was bonded into a schedule 40 pipe and boostered with a 10.2cm × 25.4cm(4" × 10") PBXN-7 equivalent booster. Average/steady state detonation velocity over the entire charge was 6195 meters/second.

In order to decrease the overall composition cost, a decision was made to evaluate the effect of larger particle size aluminum powder. Two additional compositions were manufactured in which the only difference was the type and particle size of the aluminum powders, both of which were manufactured by Alcan. The aluminum types evaluated were designated as X-82 (18μ) and X-81 (17μ). Lab scale sensitivities (i.e. impact and friction) for the compositions containing the larger particle size aluminum powder were significantly less sensitive than compositions manufactured earlier containing 5μ aluminum. However, intermediate scale sensitivities (i.e. critical diameter and card gap) indicated that the composition containing the larger size Al powder was somewhat more sensitive than the 5μ analog. The composition containing the 18μ aluminum powder (DTS-14002) had the lowest viscosity (1.5 kp@93℃) and best flow characteristics, however, the composition containing the 17μ aluminum powder was significantly more vacuum thermally stable than the composition containing 18μ Al (0.276 cc/g-vs.-0.892 cc/g). The 17μ and 18μ aluminum cost ($3.06/kg and $3.01/kg) was significantly lower compared to the 5μ aluminum powder ($11/kg). Additionally, both X-81 and X-82 aluminum powders are available in quantities required for large production volumes. It is calculated that (at an NTO cost of $11/kg) the raw material cost for a composition containing X-81 Al would be $6.07/kg ($2.76/lb.) compared to $7.74/kg ($3.52/lb.) for the composition containing the 5μ (S-400) Al. In addition to the above advantages of the X-81 Al, Parr bomb analysis indicated that the composition containing X-81 Al was significantly more thermally reactive than either of the other compositions containing either the S-400 or X-82 Al types, and therefore should result in improved air blast characteristics. Detailed information about the Parr bomb technique and test results will be presented in a subsequent paper. A composition containing 23% 17μ Al (DTS-14009) was scaled up and tested.

**Results:**

Table 4 details a summary of the sensitivity, performance and physical properties of DTS-14009.

**Conclusions:**

The formulation, characterization and scale-up of thermoplastic analogs of PBXW-124/125 was successfully accomplished in the first two phases of this program. Several important conclusions can be drawn based on the results reported and subsequent data from performance and sensitivity tests. Detailed performance and sensitivity information will be published in subsequent papers, however, the following conclusions are presented.

1. Thermoplastic analogs of PBXW-124/125 can be successfully processed in Baker-Perkins mixers. Based on viscosity and flow measurements, the authors are confident that these formulations can also be processed in steam kettle equipment since inert analogs of these formulations (employing the same binder) have successfully been processed in steam kettle equipment.
2. The composition DTS-14009 (TE-T7005) which contained 17μ low cost aluminum had a higher detonation velocity (6434 m/sec) and lower critical diameter (5.08cm) than composition DTS-13998 which contained 5μ aluminum, and had a detonation velocity of 6195 m/sec (when tested at a diameter of 8.9 cm (3.5 in.) confined) and a critical diameter of 6.35 cm (2.5 in). The NOL and ELS Gap Tests for DTS-14009 (NOL+65/−64, ELS+57/−52 kbars) showed slightly greater sensitivity than the composition containing the 5μ aluminum, DTS-13998 (NOL+63.5/−85, ELS+52.5/−48 kbars). The decreased critical diameter and increased shock sensitivity and performance associated with the larger particle size aluminum is explained by the theory that the aluminum powder acts as a buffer to help retard the propagation of a detonation wave. The 5μ aluminum powder, therefore, would have a much larger surface area and would help dampen the detonation wave resulting in both decreased sensitivity and performance as noted above.
3. The intermediate scale performance (detonation velocity) and sensitivity (card gap) values of the thermoplastic analog formulations were closely related to the comparable cast-cure HTPB/IPDI PBXW-124/125 formulations. The NOL and ELS Gap sensitivity is almost exactly the same as PBXW-124/125. The much harder polymer matrix does not seem to affect the card gap sen-

sitivity. In fact, subsequent bullet, fragment and sympathetic detonation results on DTS-13998 (later designated TE-T 7005) yielded much milder responses than the comparable PBX-124/125 HTPB analogs. These results themselves dispute the long held (but unjustified) belief that a "soft and pliable" binder was necessary to insure mild response to bullet/fragment impact testing. The sponsors of this apparently false theory failed to recognize that materials even as soft as Jell-O, when exposed to pressures characteristic of a detonation, will in fact become compressed to the point that they approach stress/strain characteristics resembling concrete. Therefore, selection of a binder which is: much less reactive than HTPB; which absorbs input energy by melting rather than transmitting the energy to the energetic solids and; which also insures significant coating and protection of each individual reactive particle is much more important with regards to mild bullet/fragment impact response than the physical properties of the binder.

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## 溶解性で注型可能な汎用不感性高性能爆薬の組成

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熱可塑性でないPBXW-124/125と同等になるような熱可塑性爆薬をつくることを試みた。実用サイズまでスケールアップすることにより不感性高性能爆薬の特性を求めた。試験結果は本組成が蒸気加熱を用いた製造装置によるものと同等であることを示した。本研究で用いた組成物はベーカーパーキンスのミキサーによって製造されたが，その製造性は蒸気加熱による製造方法と同等であることがわかった。爆薬として中程度の性能と感度特性(爆轟速度，カードギャップなど)はPBXW-124/125の特性に近いことを示した。この組成をスケールアップして試験したものはTE-T 7005として登録された。大規模な試験結果によると，本研究による組成物は標準的なPBXと同等な性能でありながら極めて低い感度を有していることがわかった。

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