Performance test results of a melt castable, general purpose, insensitive high explosive

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The thermoplastic explosive (TE-T7005) was developed as a General Purpose (GP) Insensitive High Explosive (IHE) candidate due to a number of favorable factors including: low small scale sensitivity characteristics; low processing cost; theoretical high performance; re-meltability (with associated economic and environmental benefits); and potential endothermic characteristics during cook-off.[1, 2] This paper will report on large-scale performance test results (airblast impulse, airblast overpressure and fragment velocity) for the composition TE-T7005. Airblast impulse, airblast peak overpressure and fragment velocity results are compared with those of the explosives H-6, PBX-109, Tritonal, and HTPB analogs of TE-T7005 (PBXW-124 and PBXW-125).[3] The fragment velocity performance for TE-T7005 (5914 ft/sec) was 90% of H-6 and was between PBX-109 (6249 ft/sec) and Tritonal (5609 ft/sec). Peak overpressure values for TE-T7005 were slightly superior to H-6 while overpressure impulse values were essentially equivalent to H-6. TE-T7005 explosive was superior to the HTPB analogs with regards to fragment performance and significantly superior to the HTPB analogs with regards to blast performance.

Test description:

TE-T7005 explosive was cast into a split mold fixture having an interior diameter comparable to the test unit interior diameter. The test unit is known as a Naturally Fragmenting Test Unit (NFTU). The NFTU is manufactured from mild steel and consists of a right circular cylinder with exterior dimensions of 8 in. × 16 in. (20.32 cm × 40.62 cm) and has a wall thickness of 0.375 in. (0.95 cm). Additionally, the NFTU is closed at the bottom with an equivalent wall thickness and open at the top. After the TE-T7005 explosive was loaded into the casting fixture (which actually had a height of 22 in. (55.88 cm)) and allowed to cool and solidify, the explosive was removed from the mold. The explosive was then x-rayed through two mutually perpendicular, transverse axes (0° and 90°) to verify that voids did not exist over a length of at least 17". Once radiographic inspection verified that no significant voids existed in the charge, the explosive was placed in a wooden miter box. The explosive was then manually cut with a coarse 7 bit/inch hand saw (using the x-ray film as a guide to insure that cutting excluded any voids) to a length of 16 in. (40.64 cm). A piece of 20 grit sand paper was adhered to a 12 in. × 12 in. × 0.5 in. (30.5 cm × 30.5 cm × 1.3 cm) piece of plywood and both of the explosive's ends were smoothed to ensure that flat surfaces would be exposed to the booster and bottom closure plate. Prior to insertion of the explosive charge into the NFTU case, a 1/4 in. diameter hole was drilled into the end of the NFTU and the NFTU and explosive charge were both weighed. The NFTU was then coated on the interior with RTV (R-81) to which an appropriate amount of Dibutyl Tin Di-Laurate (DBTDL) was added as a cure agent/catalyst. The explosive charge was also liberally coated with the same RTV mixture and then inserted into the NFTU case. The hole previously drilled into the end of the NFTU permitted air and excess RTV to escape as there was minimal clearance between the explosive and NFTU wall. Once the RTV was cured, the charge was thus firmly bonded into the NFTU case and the excess RTV was trimmed from the exterior of the case and exposed explosive charge. The exposed end of the explosive was then

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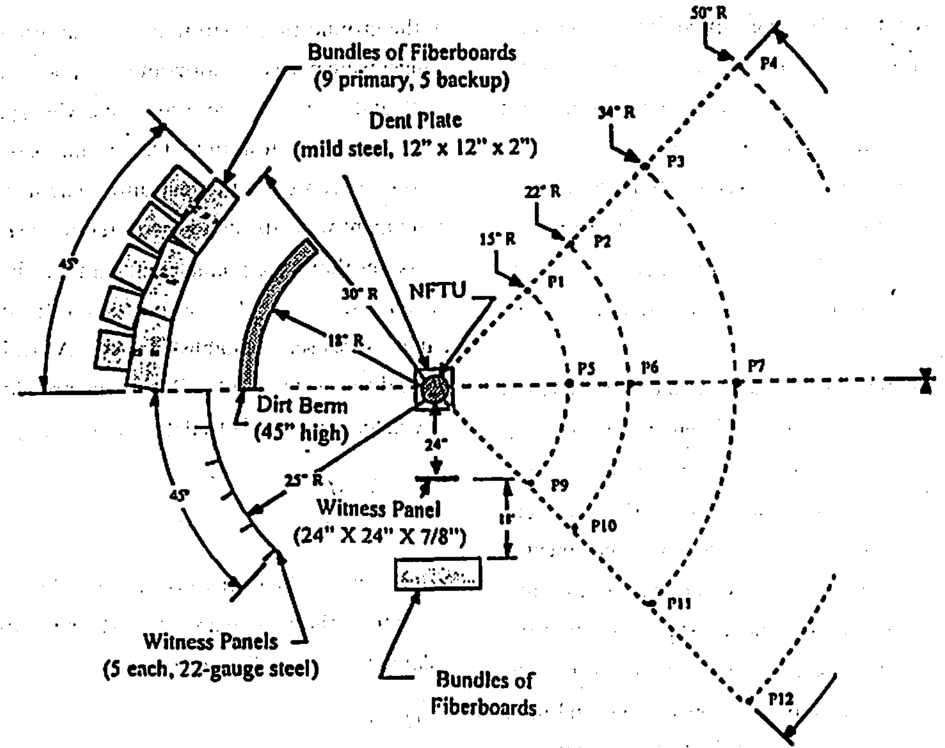

Fig. 1 Arena test configuration

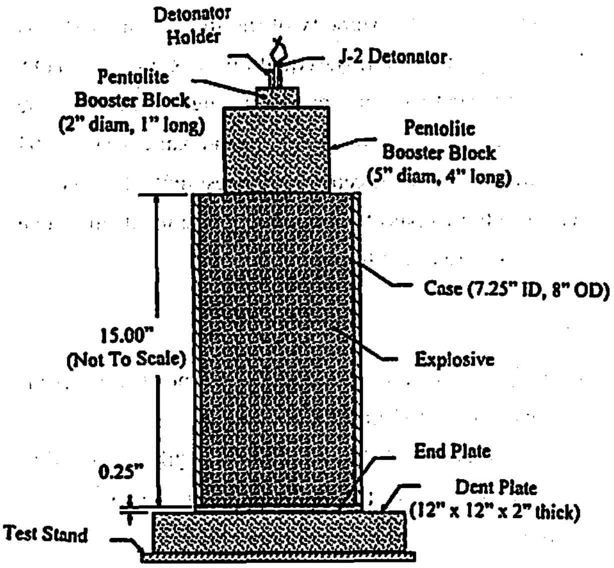

Fig. 2 NFTU/initiation assembly

covered with aluminum foil, securely taped and shipped to the explosive testing facility for performance testing.

Performance tests were conducted in an open area which is surrounded by witness panels and blast gauges causing the test area to appear somewhat like an arena, thus the name "Arena Testing" was given to tests which take place in this environment (Fig. 1). The objective of the Arena Test is to collect data to evaluate blast pressure and fragmentation characteristics of experimental explosives. Blast and fragmentation characteristics of TE-T7005 were measured and compared to three baseline explosives: H-6; Tritonal; and PBX-109 plus two HTPB analogs (PBXW-124 and PBXW-125). Two NFTUs were used to collect the required data for each explosive. Each test unit was equipped with an initiation assembly that consisted of a J-2 detonator and a Pentolite booster. The Pentolite booster consisted of a 2 in. (5. 08 cm) diameter × 1 in. (2. 54 cm) long Pentolite block and a 5 in. (12. 7 cm) diameter × 4 in. (10. 16) long Pentolite block. Fig.2 illustrates a test unit configured with an initiation assembly.

Procedure and theory:

Prior to the test, each test unit was again x-rayed through two mutually perpendicular, transverse axes (0° and 90°). Two high speed motion picture cameras (16, 000 frames/second) were used to collect fragment velocity data during each test. The cameras were positioned to provide complete photographic coverage of the scintillations which occurred at the 22 gauge steel witness panels (to permit calculation of fragment velocity) and provide coverage of the test unit. A real time signal was recorded on each photographic film for use in establishing event times. A slit was placed in the witness panels in line with the high speed camera and the test unit. Zero time was established at the point when first light was observed through the slit from the detonation process. Fragment velocity was determined from visual observation (via high speed film) of the fragment impact scintillations on the witness panels and related to the time from first light and camera frame speed upon which the real time signal was based.

Still photographs were also taken to obtain 8 in. × 10 in. (20. cm × 25 cm) color prints of the test setups and debris. Additionally, a VHS color video cassette recorder was used to document the test setup, the test, and post test observations.

Bundles of fiberboards and the 22 gauge witness panels were placed such that fragment and fragment velocity data was collected between 85° and 105° polar angles and within 45° azimuthal zones. The bundles of fiberboards were marked with the 85° to 105° polar zones (in 5° increments) and 45° azimuthal zones on the side facing the test unit. The test unit was placed onto the test stand such that the longitudinal axis of the test unit was oriented vertically and the end to be initiated was at the top as shown in Fig. 2. The booster was placed on top of the test unit such that the booster was centered and in contact with the explosive. Duct tape was used to support the booster assembly. The detonator holder was placed against the booster so that the holder was centered and in contact with the booster. Duct tape was also used to support the detonator holder. The test setup was photographed and video taped. The area was then cleared, with the exception of the Firing Director and one ordnance man who attached the shorted firing lead to the J-2 detonator. The J-2 electric detonator was inserted into the detonator holder such that the forward end of the detonator was in contact with the booster. A visual inspection of the area was then made to ensure that all personnel were clear of the area followed by a head count to ensure that all personnel were within the sheltered areas. Final adjustments to the instrumentation recording equipment were made and then the firing lead was attached to the firing board, the firing lead was unshorted, the control key inserted, and the test unit was detonated. After photographic and electronic instrumentation data was collected, the witness panels were moved to a nearby facility for the calculation of fragment hole count followed by fragment size distribution data calculations. New witness panels and fiberboards were moved into the test site, repairs were made to the test arena as required, the test setup was reconstructed, and the test was then repeated with a duplicate charge.

A total of 12 blast gauges were used to measure blast overpressure during each test. All of the gauges were placed in the ground plane within a 90° azimuthal sector. The gauges were placed at horizontal distances of 15 ft., 22 ft., 34 ft. and 50 ft. from the vertical line which passes through the center of the test unit. The ground plane was 104 in. below the center of the test unit. The instrumentation equipment was adjusted as required to measure the blast pressures that were predicted at standoff distances of 15, 22, 34 and 50 feet. The output signals from the pressure gauges were used to establish Time-of-Arrival (TOA) data for individual test units. Peak over-pressures were then calculated using the TOA data and the following equation:

$$p=\frac{7(M^2-1)}{6}P$$

Where: p = peak overpressure, M = Mach number and P = atmospheric pressure. The Mach numbers were calculated from the following equation:[4]

$$M=u/a$$

Where: u = velocity of the shock front, and a = sonic velocity. Elements of the Mach number were determined as follows. First the velocity of the shock front (u) was obtained by establishing the equations of Range -vs.- TOA for specific vectors from the "zero range" location. The "zero range" location was in the ground plane, 104 in (264 cm) directly below the center of the test unit. The vectors were selected to pass through the gauge locations. The equations were of the following form:

$$r=bt^c$$

Where: r = range, b = constant, t = time of shock front propagation (TOA) and C = constant.

Next, range vs. TOA equations were differentiated to obtain the velocity of the shock front (u) for each gauge location. The equations were of the following form:

$$u=r'=bct^{c-1}$$

Where r' = derivative of the range vs. TOA equation, b = constant, c = constant and t = time of arrival. The sonic velocity (a) was measured at the test site at the time of test.

The recorded blast pressure data were adequate to provide a first order approximation of the blast pressure and impulse parameters when the data was considered collectively. The following equation was fitted to the experimental data from each pressure gauge.

$$p=P(1-t/d)e^{-at/d}$$

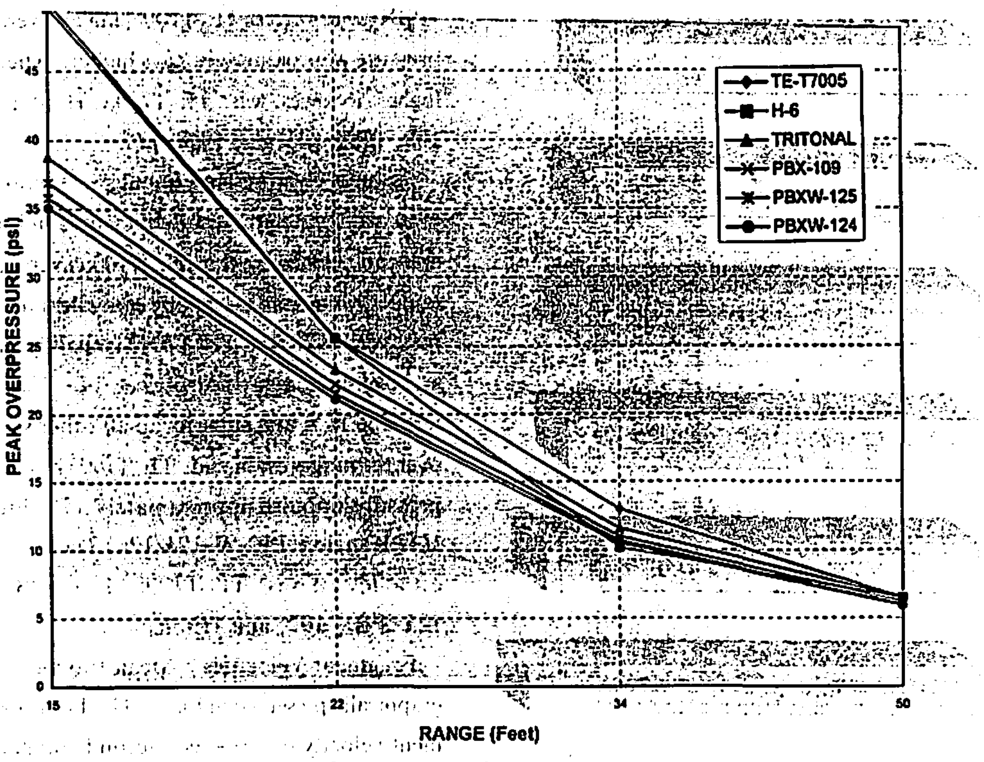

Fig. 3 Average peak overpressures

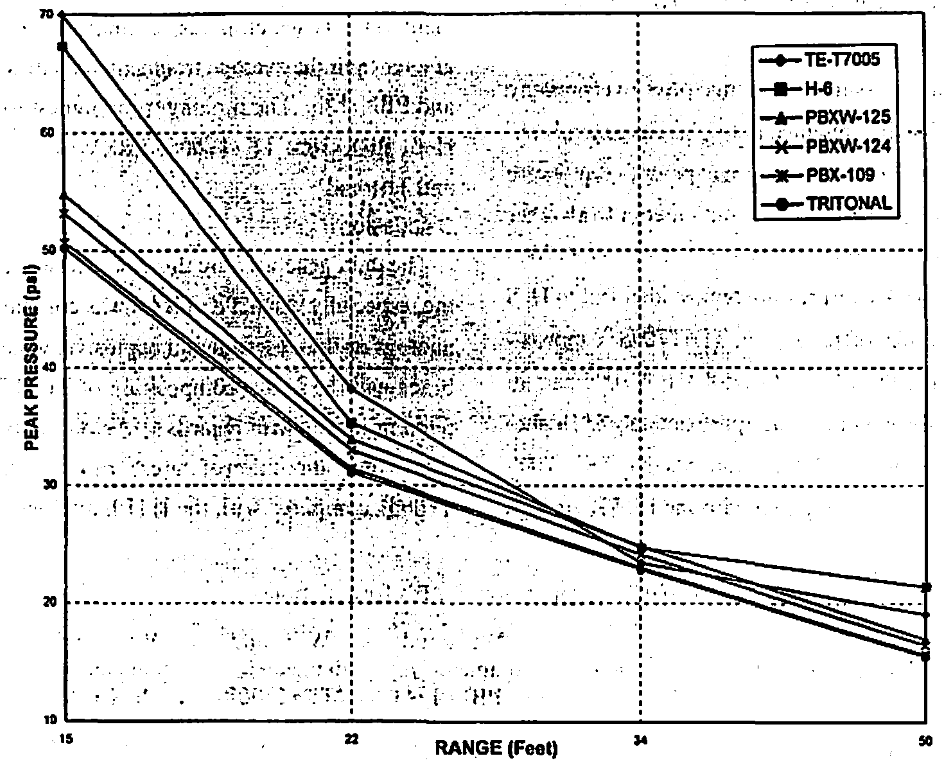

Fig. 4 Average positive impulse for GP IHE compositions

Where: p = overpressure; P = peak overpressure; t = time, d = duration of overpressure, e = base of natural logarithms (2.71828) and a = decay parameter.

Data:

Adequate test data was collected to compare the general blast and fragmentation characteristics of TE-T7005 with H-6, PBX-109, Tritonal and HTPB analogs of TE-T7005 (PBXW-124 and PBXW-125). Average peak pressures and average positive impulses are detailed in Fig. 3 and 4. Mean fragment velocities are detailed in Fig. 5.

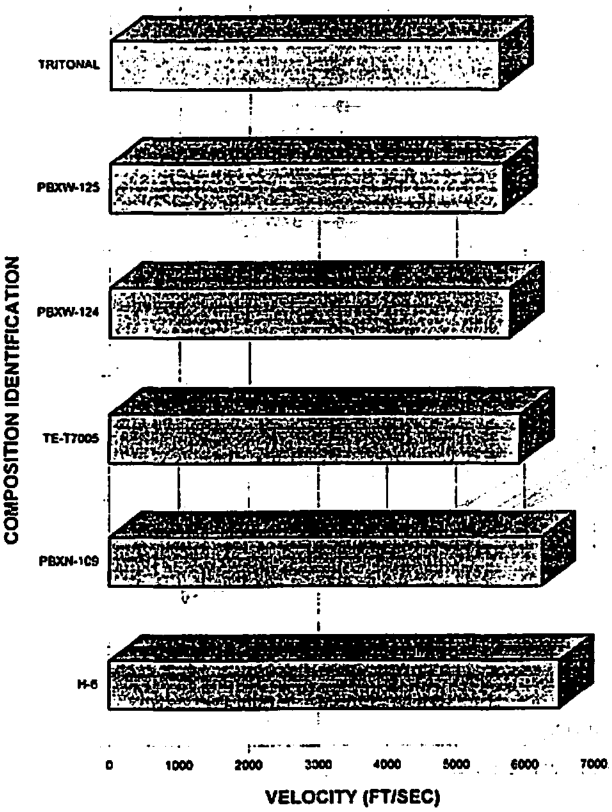

Fig. 5 Mean fragment velocity for GP IHE compositions

Airblast Peak Pressures: Average peak overpressure values are graphically presented in Fig. 3. The general conclusions are that TE-T7005 average peak overpressure values are slightly superior to H-6 and superior to all other standards tested. At closer ranges (15-22 feet), TE-T7005 has an average peak overpressure almost identical to H-6 while over the range of 22-50 feet, TE-T7005 is approximately 5% higher than H-6. Overall, TE-T7005 had an average peak overpressure value approximately 4% higher than H-6, the highest of all the standards that TE-T7005 was compared with. Compared with the HTPB analogs (PBXW-124/125) TE-T7005 had an average peak overpressure approximately 25% higher. The ranking from highest to lowest was: TE-T7005; H-6; Tritonal; PBX-109; PBX-125; and PBX-124.

Airblast Overpressure Impulse - Average positive impulse values are graphically presented in Fig. 4. The general conclusions are that TE-T7005 average overpressure impulse values are essentially equivalent to H-6. Over the range of 15-28 feet, TE-T7005 is slightly superior to H-6 and over the range of 28-50 feet, TE-T7005 is slightly inferior to H-6 and superior to all other standards tested over the ranges evaluated. TE-T7005 has an average overpressure impulse approximately 17% higher than the HTPB analogs PBXW-124/125. The ranking from highest to lowest was: TE-T7005; H-6; PBX-125; PBX-124; PBX-109; and Tritonal.

Fragment Velocities - Mean fragment velocities are graphically presented in Fig. 5. TE-T7005 has a mean fragment velocity of 5914 feet/second compared with 6249 feet/second for PBX-109 (with 64% RDX) and 6503 feet/second for H-6. However, TE-T7005 has a mean fragment velocity which is approximately 190 feet/second greater than the average fragment velocities of PBX-124 and PBX-125. The ranking from highest to lowest was: H-6; PBX-109; TE-T7005; PBXW-124; PBXW-125; and Tritonal.

Discussion:

The data generated by this research was quite surprising, especially when TE-T7005 was compared to HTPB analogs of the experimental explosive, which essentially bracketed the solid's composition of TE-T7005 but differed primarily with regards to the binder type. Table 1 details the composition of the experimental explosive (TE-T7005) compared with the HTPB analogs (PBXW-124

Table 1 Composition of PBX formulations

INGREDIENT	VENDOR	Wt.% and diameter(μ) (PBX-124)	Wt.% and diameter(μ) (TE-T7005)	Wt.% and diameter(μ) (PBX-125)
HTPB+E702	-	4.85+0.05	N/A	4.44+0.05
IPDI+TPB	-	0.46+0.01	N/A	0.45+0.01
IDP+Lecithin	-	7.23+0.4	N/A	6.65+0.4
TTB-531	Thiokol	N/A	12	N/A
Al Powder	Reynolds	20/18	23/17	26/18
AP	Kerr McGee	20/200	20/200	20/200
NTO	Olin	27/250	25/250	22/250
RDX	Holston AAP	20/4	20/4	20/4

and PBXW-125). The other significant variables between the HTPB analogs and the experimental explosive are the percentages of aluminum powder and NTO. However, as indicated by Table 1, TE-T7005 falls between the HTPB analogs (with regards to aluminum and NTO concentration) and therefore, TE-T7005 should theoretically fall between these two compositions with regards to performance. The only other difference between TE-T7005 and PBXW-124/125 are the aluminum powder particle size and type, however, the aluminum powder vendor is the same.

As indicated by the data, the average peak overpressures, average overpressure impulses and mean fragment velocities for TE-T7005 were significantly greater than either of the HTPB analogs of TE-T7005 (PBXW-124/125). A potential explanation, firstly, of this difference (since the compositions PBXW-124/125 essentially bracket TE-T7005 with regards to solid's content) is that due to the much more fluid nature of the thermoplastic binder, energetic solids (i.e. RDX and NTO) are much more dispersed in the binder matrix thus permitting a more uniform detonation process. The binder type is a Thiokol Corp. Proprietary binder known as TTB-531 (which has a melting point of 82℃) and is essentially a low molecular weight (500 MW) polyethylene hydrocarbon mixed with a plasticizer in an 80/20 ratio.[6] A second, more plausible theory is that energy which would normally be utilized for cured HTPB bond breakage is now available for fragment breakup and acceleration as well as for fuel oxidation since both fragment velocities and airblast values of TE-T7005 are significantly higher than the HTPB analogs. A third, and possibly supplemental theory, is that the aluminum powder itself may contain a type of reactant catalyst (with regards to aluminum combustion as it relates to air blast) thus resulting in higher airblast characteristics. An earlier paper on this subject revealed that differences in aluminum type (with particle size differences of only 1 μm) resulted in tremendous differences in burn rate and impetus of explosives which were otherwise essentially identical. Even compared to a composition containing 5 μm aluminum (which contains a much higher surface area and associated aluminum oxide content, a known burn rate catalyst) burn rates and impetus of the composition containing the aluminum type (X-81) used to manufacture TE-T7005 were much higher.

Conclusions:

- The data demonstrates that TE-T7005 is a highly effective high explosive composition especially with regards to airblast characteristics. Air blast performance comparable to H-6 (which contains 45% RDX, 30% TNT, 5% D-2 wax and 20% Aluminum powder) was observed. This was quite surprising considering the fact that H-6 contains a much higher percentage of traditional high explosives.
- Significant performance differences (especially airblast) were observed between TE-T7005 and similar compositions containing HTPB binder instead of the meltable binder TTB-531 that was contained in TE-T7005. Performance values for other explosive compositions (manufactured with similar low molecular weight binders) may result in significantly improved performance (in terms of increased fragment velocities and airblast characteristics) relative to HTPB based compositions.
- Incidental to the manufacturing process, larger scale (5-Gallon) TNT melt kettle processability (with an inert equivalent to TE-T7005) was also demonstrated in this study.
- Subsequent large-scale impact sensitivity testing (Bullet Impact, Fragment Impact and Sympathetic Detonation) verified vastly improved sensitivity characteristics of TE-T7005 relative to the HTPB analogs. Impact sensitivity test results will be published at a later date.

Recommendations:

1. Verification of improved airblast and fragmentation characteristics (with binder type as the only variable) should occur with different compositions to determine if the previously proposed theory is valid. This theory proposes that energy which would normally be utilized for cured HTPB bond breakage may now be available for fragment breakup and acceleration as well as for fuel oxidation (due to the lower molecular weight of the binder) because the data shows improvements in both fragment velocities and airblast values of TE-T7005 when compared to the HTPB analogs PBXW-124/125.
2. Further evaluation of the specific aluminum employed for TE-T7005 (X-81) as well as other aluminum types should occur to determine if any catalytic activity may be improving airblast characteristics. While this theory may sound far-fetched, other data has revealed that differences in aluminum types (with particle size differences of only 1 μm) resulted in tremendous differences in burn rate and impetus of explosives, which were oth-

erwise essentially identical.

Acknowledgments

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融解性直填可能な汎用不感性爆薬の性能試験結果について

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熱可塑性爆薬(TE-T7005)は，低感度特性，低製造コスト，高い理論性能，経済性と環境問題の観点から有利である再溶解性を有し，さらにクックオフ時には吸熱性となる特性を有することから，汎用の不感性高性能爆薬(IHE)として開発された。本論文では大規模な実験によって得られた，TE-T7005爆薬の衝撃値，頂圧，破片速度の結果を爆薬H-6，PBX-106，トリトナール，それにHTPBを用いたTE-T7005爆薬と比較して示す。破片速度性能は1804 m/sであり，H-6の90%に達しており，PBX-109(1906m/s)とトリトナール(1711m/s)の中間にあることが確認された。衝撃値についてはH-6と同等であるが，頂圧はH-6よりもわずかに優れていることがわかった。またHTPBを用いたTE-T7005と比較し破片性能に優れ，さらに爆風性能では著しく高性能であることがわかった。

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