Large-scale impact sensitivity test results of a melt castable, general purpose, insensitive high explosive

by Theodore S. SUMRALL*

The aluminized eutectic explosive (TE-E7007) was developed as an economical, melt castable, general purpose (GP), insensitive high explosive (IHE) candidate due to a number of factors including: low small scale sensitivity characteristics; low raw-material and processing costs; theoretical high performance and low large-scale impact sensitivity; re-meltability (with associated economic and environmental benefits); and potential endothermic characteristics during cook-off.[1,2] Subsequent large-scale performance test results verified theoretical performance predictions[3,4] and a follow up effort to determine large-scale impact sensitivity characteristics occurred. This paper will report on large-scale impact sensitivity test results (bullet impact, fragment impact and sympathetic detonation) for the composition TE-E7007. Without exception, all units tested resulted in either an explosion or detonation response. These responses were deemed to be unacceptable from overall safety criteria and therefore the explosive TE-E7007 was not subjected to cook-off sensitivity testing in order to conserve test funds.

Test hardware description:

TE-E7007 explosive was cast directly into a number of test units. The test units are known as modified naturally fragmenting test units (NFTU) or heavy wall test units (HWTU). 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). The HWTU also consists of a right circular cylinder with similar exterior dimensions, but with a wall thickeness of 0.5 in. and end plate thickess of 1.0 in. After the TE-E7007 explosive was allowed to cool and solidify, the explosive was x-rayed through two mutually perpendicular, transverse axes (0° and 90°). The exposed end of the explosive was then covered with an end plate and shipped to the explosive testing facility. Sensitivity tests were conducted in accordance with MIL-STD-2105B.

Theory:

Explosives are basically susceptible to two types of initiation methods, i.e., thermal initiation or deflagration to detonation transition (DDT) and shock initiation or shock to detonation transfer (SDT). The latter method is the method utilized for intentional explosive initiation (by means of a blasting cap or booster) but is often the means by which unintentional initiation of explosives also occurs as a result of impact from other sources such as adjacent explosives. The most severe test of shock sensitivity involves metal to metal impact by means of either a bullet, high velocity fragment and/or sympathetic detonation of an adjacent explosive where a metal projectile penetrates the metal case of the test unit. The various impact tests are designed to determine the sensitivity of an explosive composition to high velocity impact and assessment of subsequent shock to detonation transfer (SDT). A number of factors can increase the sensitivity of an explosive beyond its normal sensitivity characteristics. One factor is voids. Introduction of voids (i.e. by micro-balloons or gassing) is a well known method to increase sensitivity of blasting agents to the point that the explosive becomes detonable with a small explosive input (i.e. No. 8 blasting cap).

Impact tests subject a certain minimum area of explosive to shock at a certain minimum pressure. For projec-

---

Received on October 23, 1997

*Advanced Technologies and Studies Department, Sverdrup Technology, Inc.
214 Government Street, Niceville, Florida 32578, USA
TEL USA-904-729-6421
FAX USA-904-729-6400

tile impact scenarios, this requires a certain minimum projectile velocity, referred to as the "critical impact velocity". The larger the area impacted, the lower the critical impact velocity. Therefore, impactors with the lowest convexity (flat faces) are most effective at initiating detonation by an SDT mechanism. However, flat-faced impact upon barriers is more likely than edge or corner impacts to shatter the projectile so that subsequent penetration and shock-energy transfer capabilities may both be reduced.[6)] However, by accelerating the projectiles (fragments) to a minimum velocity of 8300 feet/second, a maximum shock transfer is accomplished.

When a metal projectile strikes an explosive, four reactions can be induced: detonation; explosion; burning; or no reaction. A detonation is defined as a high order reaction which pierces a 1/2 in. thick mild steel witness plate with a hole that is approximately the same diameter as the acceptor charge case (the NFTU in this example) and is classified as a "Class-I Reaction". An explosion is a lower order violent high pressure reaction that can damage the test stand, the case material/explosive, and throws large fragments of case material or explosive ≥ 50 feet (15.24 m). In an explosion, the witness plate does not sustain damage and is clasified as a "Class-II" or "Class-III Reaction". A sustained burn reaction consists of energetic material ignition and burning until all of the explosive is consumed. This usually takes a number of minutes depending on the type of explosive, the mass of the explosive and level of confinement. Burning is classified as a "Class-IV" or "Class-V Reaction", again depending on the reaction severity.

Bullet impact test procedure:

The bullet impact test is conducted to determine the reaction of the test item when impacted by one to three 0.50 caliber type projectiles aimed at a common point at a velocity of 2800 ± 200 ft/sec (850 ± 60 m/sec).[5)] The firing interval was within 80 ± 40 msec. Two test items were tested with the impacting bullets penetrating the explosive material. Airblast overpressures were measured to ascertain the explosive response level. Also, witness plates were positioned to provide evidence of the severity of the reaction. The bullet impact velocity was measured using electronic velocity screens. A graphite element was placed across the muzzle of each gun to determine when the projectile exited the muzzle by opening an electrical circuit. Three 16-mm motion picture cameras were used to record the test item reaction. Four blast gauges were used to measure the overpressure produced by the reaction of the test unit. All of the gauges were placed in the horizontal plane which passed through the geometric center of the test unit at ranges of 15, 22, 34, and 50 ft. from the vertical line that passed through the center of the test unit.

Fig. 1 Bullet impact test results of S/N 1755

Bullet impact test results:

Two test units containing explosive TE-T7007 (identified as S/N 1755 and S/N 1758) were tested. The reaction for the first test unit (S/N 1755) was judged to be a mild explosion (Fig. 1). The reaction occurred upon impact of the first bullet. The duration of the reaction was such that the test unit debris were ejected from the test fixture before arrival of the second and third bullets. The case split into large fragments that were ejected a distance of 10 ft. Liner material was observed on the end plate and case fragments that were recovered from the test site. A large quantity of explosive material was scattered about the test site. No small fragments (which would be evidence of a detonation reaction) penetrated the witness panel. The dent plate was not damaged. The reaction generated a propagating blast pressure that had a magnitude of 4.8 psi at a range distance of 15 ft and an impulse of 24.3 psi-ms at a range distance of 15 ft. The velocity of the first bullet was 2868 ft/sec. Intentional detonation of a similar unit (during arena testing) yielded an average peak overpressure of approximately 39 psi at a range distance of 15 ft. and an impulse of approximately 55 psi-ms at a range distance of 15 ft. This is estimated to be an equivalent energy release of approximately 12% (with regards to peak pressure) and 44% (with regards to impulse) when compared to the TE-E7007 units previously subjected to arena testing.

The reaction for the second test unit (S/N 1758) was

Fig. 2 Bullet impact test results of S/N 1758

also judged to be a mild explosion and occurred upon impact of the first bullet (Fig. 2). The duration of the reaction was such that the test unit debris were ejected from the test fixture before anival of the second and third bullets. The case split into large fragments that were ejected a distance of 369 ft. Liner material was observed on the end plate and case fragments which were recovered from the test site. A large quantity of explosive material was scattered about the test site. No small fragments penetrated the witness panel. The dent plate was not damaged. The reaction generated a propagating blast pressure that had a magnitude of 4. 9 psi and an impulse of 25. 0 psi-ms at a range distance of 15 ft. The velocity of the first bullet was 2902 ft/sec. This translates to an equivalent energy release of approximately 12% (with regards to peak pressure) and 57% (with regards to impulse) when compared to the samples subjected to arena testing.

Fragment impact test procedure:

Prior to test set up, each unit was x-rayed through two mutually perpendicular, transverse axes. Each modified test unit (with additional end confinement) was placed on a 1-ft by 1-ft by 2-in. steel dent plate that had been placed on a wooden test stand. The longitudinal axis of the test unit was oriented vertically and its geometric center was approximately 51 in. above the ground plane. Two metal banding straps were used to secure the test unit and the dent plate to the test stand. One 22-gauge steel witness panel was placed near the test unit to collect fragment velocity data with high-speed 16-mm cameras. Another 22-gauge steel witness panel was placed behind the test unit to monitor test unit debris. A 2-ft by 2-ft by 7/8-in. steel witness panel was placed at a 2-ft standoff distance from the test unit, and fiberboards were positioned behind the panel to catch the witness panel and fragments. The launching charge (125 lb. of Comp-B explosive) was placed on a test stand at a nominal distance of 16 ft from the test unit. The launching charge was adjusted to the same elevation as the test unit, and the fragment mat was then attached to the launching charge. An electrical sensor was attached to the fragment mat to detect first motion and the signal from this circuit was recorded on each camera and data recorder to provide a common data reference. An electronic velocity screen was placed in front of the test unit or wrapped around the test unit to collect fragment velocity data. Test events were documented using a VHS videocassette recorder in conjunction with a color, closed-circuit television system. The video cassette record was annotated with the date and time of each test. The launching charge was then detonated using a J-2 blasting cap and a 1-in. diameter by 1-in. length CH-6 booster pellet. Upon completion of the test, test unit debris was recovered, and the size and location of each piece of debris was noted.

·Fragment velocity data was collected via high-speed photography. The time base was established by counting the number of frames between the first light caused by the initiation of the launching charge and the first light caused by impact of the fragments on the test unit, and then adjusting the time base by the length of time required for the detonation to propagate throughout the booster and launching charge to accelerate the fragments. Fragment velocities were calculated with the following equation.

$$V=\left[\frac{D}{\frac{F}{R}-T}\right]$$

Where: V=velocity of fragments, D=distance between fragment mat and surface of test unit, F=frames on photographic film between time when launching charge was initiated and time when fragments impacted test unit, R=rate of frames on photographic film, and T=time for detonation to propagate through booster and launching charge.

The time for the detonation to propagate through the booster and the propelling charge was established as follows:

$$T=\frac{\text{Booster length}}{\text{Booster detonation rate}}+\frac{\text{Launching charge length}}{\begin{array}{c}\text{Launching charge}\\ \text{detonation rate}\end{array}}$$

$$T=\frac{0.0254\text{m}}{8550\text{m/sec}}+\frac{0.8128\text{m}}{7840\text{m/sec}}=107\mu\text{sec}$$

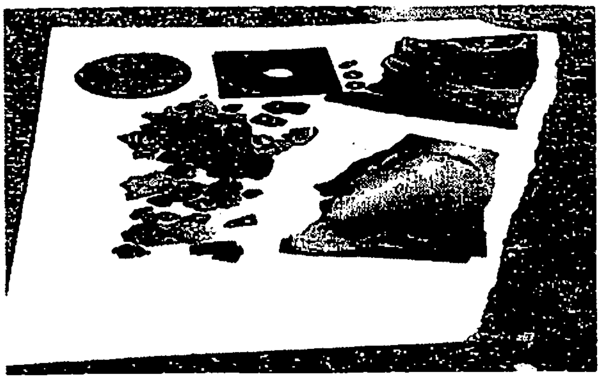

Fig. 3 Fragment impact test results of S/N 1759

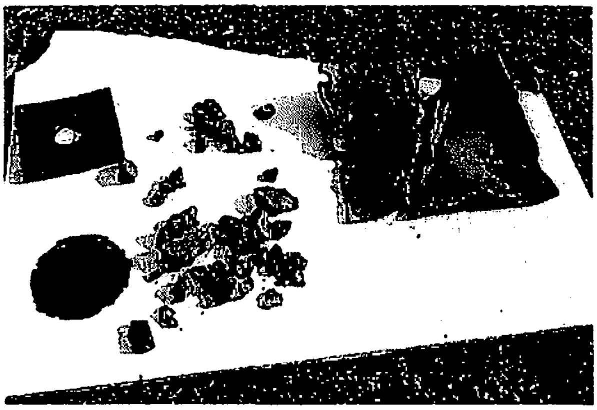

Fig. 4 Fragment impact test results of S/N 1760

Fragment impact test results:

Two modified test units containing explosive TE-T7007 (identified as S/N T1759 and S/N T1760) were tested. The reaction for the first test unit (S/N T1759) was judged to be an explosion (Fig. 3). There were four fragment impacts. The average velocity of the fragments was 8252 ft/sec. The case of test unit T1759 split into large fragments that were ejected a distance of 1275 ft. Liner material was observed on the large case fragments. The end plate was found 2. 5 ft from the "zero" range location. Explosive and liner material were attached to the end plate. The dent plate was not damaged. Explosive material was scattered about the test site and some explosive became embedded in the fiberboard material used to collect test unit debris. Blast pressure from the test unit interacted with the blast pressure from the fragment launching charge such that there was a canceling effect which reduced the magnitude and impulse of the resulting blast pressure at the gauge locations to values below that expected from only the launching charge. This canceling effect of the blast pressures from the test unit and the launching charge was seen by comparing the blast pressures with those recorded for a different test unit (containing PBXW-124 loaded in NFTU) that only burned in the same test setup. The amount of the canceling effect (which depends upon the relative timing of the reactions, magnitude of the blast pressures, and geometry relative to the gauge locations) could not be separated in such a manner that quantitative values could be assigned to the test unit.

The reaction of the second test unit (S/N T1760) was also judged to be an explosion (Fig. 4). There were five fragment impacts. The average velocity of the fragments was 8252 ft/sec. The case of the test unit split into large fragments that were ejected a distance of between 399-462 ft. Liner material was observed on the end plate and case fragments which were recovered from the test site. The dent plate was not damaged. Explosive material was scattered about the test site and some explosive became embedded in the fiberboard material used to collect test unit debris. No small fragments were found. Blast pressure from the test unit interacted with the blast pressure from the fragment launching charge such that there was a canceling effect which reduced the magnitude and impulse of the resulting blast pressure at the gauge locations to values below that expected only from the launching charge. This canceling effect of the blast pressures from the test unit and the launching charge was seen by comparing the blast pressures with those recorded for a test unit (PBXW-124 in NFTU) that only burned in the same test setup.

Sympathetic detonation test procedure:

Heavy wall test units (HWTU) were used to conduct the sympathetic detonation (SD) tests. Each HWTU contained approximately 34 lbs. of TE-E7007 explosive. The aft closure plate of each donor HWTU was modified to provide a 5. 125 in. diameter access hole for the booster. Each donor test unit was equipped with an initiation assembly that consisted of a J-2 detonator and a pentolite booster measuring 2 in × 1 in. pentolite block and a 5 in. × 4 in. pentolite block. One donor (S/N T1757) and two acceptor test units (S/N T1749 (at 1 in. standoff) and S/N T1761 (at 6 in. standoff)) were used for the SD tests.

A total of two 2 ft. × 2 ft. by 7/8 in. steel panels (one per acceptor test unit) were used to witness fragment distribution at a 2 ft. standoff distance from the acceptor test units. Twelve blast gauges were placed in the ground plane within a 90° azimuthal sector on one side of the test units. Fig. 5 shows the donor and two acceptor test units arranged on a 3 in. thick dent plate. High speed photography and

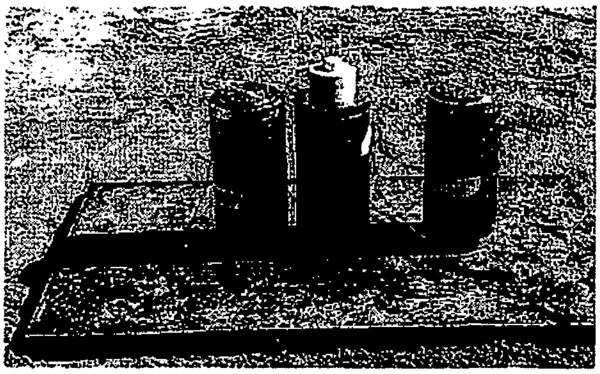

Fig. 5 Sympathetic detonation test setup S/N 1749, 1745, 1761

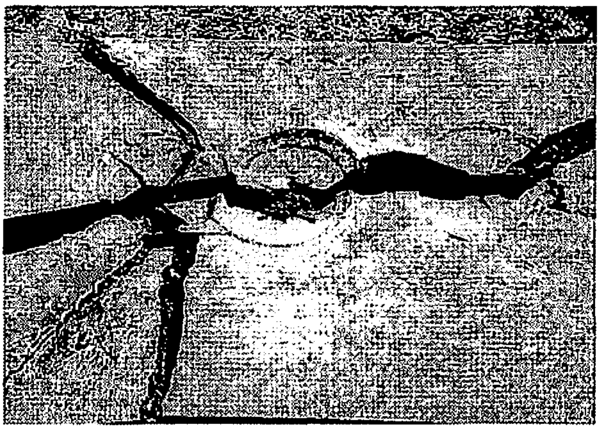

Fig. 6 Sympathetic detonation test results, S/N 1749, 1757 & 1761

color video coverage of the tests were provided.

Sympathetic detonation test results:

Both acceptor test units detonated. There was an indention in the mild steel base plate at each of the pretest locations of the three test units (Fig. 6). The indentions were 2, 1.5, and 1-in. deep at the pretest locations of the donor, acceptor at 1-in. standoff, and acceptor at 6-in. standoff, respectively. The 5-ft by 3-ft by 3-in. thick steel base plate was broken into five major pieces that were recovered from the crater caused by the reaction. The crater had a diameter of 7 ft and a depth of 3 ft. The three nose plates of the test units were recovered from the crater. Small fragments (indiciative of a detonation) were recovered from the fiberboard material used to recover debris from each of the two acceptor test units (Fig. 7). There was no explosive material found scattered about the test site nor embedded in the fiberboard material used to collect test unit debris from the acceptor test units (indicative of complete explosive reaction).

Discussion and conclusions:

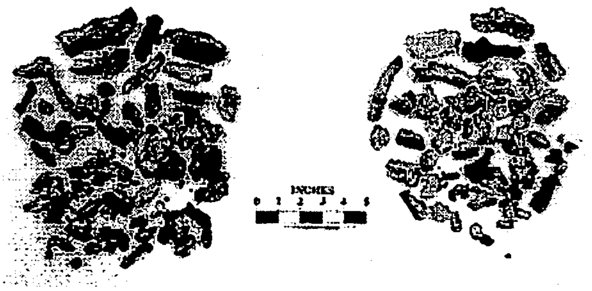

Fig. 7 Case fragments from sympathetic detonation test, SN/1749, 1757 & 1761

Table 1 Composition of TE-E7007 eutectic explosive

Ingredient	Weight percent
DCDA	10.80
AN	19.44
GN	5.76
EDDN	15.00
AP (17μm)	17.00
RDX (>4μm)	12.00

This research project entailed development of a eutectic explosive with the intended goal of high insensitivity. An intensive literature evaluation indicated that eutectic formulations offered hope for a safe high performance explosive.7) Previous work with AN/EDDN based eutectic explosive compositions revealed high insensitivity at small scales but low insensitivity at larger scales.8) However, it was hoped that by increasing the number of eutectic components to five (where each would have a much smaller percentage than prior eutectic explosives) the sensitivity of TE-E7007 would be much lower. A formulation was finalized with the composition detailed in Table 1. Further details on the explosive formulation are described in Reference-1.

Compared to previous, somewhat sensitive compositions containing AN and EDDN, the percentages of these two ingredients were lowered from 50% each to approximately 19% and 15% respectively.9) Unfortunately, as a result of the data presented in this paper, the goal of an economic, insensitive, high performance general purpose explosive remains, at present, elusive. However, poor quality test loads may be partly responsible for the results noted. Unfortunately, as a result of downsizing, critical personnel were no longer employed at the manufacturing facility during the time that the test units were loaded. Test personnel, at a different facility, noted unit weight differences as much as ± 1 kg. This much of a weight difference could account for the unanticipated test results. Excessive RDX could have been present in the units with above normal weights and x-rays revealed the presence of numerous voids in the units with below normal weights. Either situation could have resulted in higher sensitivities than normal.

A final possibility is that (since previous data indicated that AP was participating in the eutectic as evidenced by a drop in eutectic melt temperature) the 17μ AP was actually losing sufficient surface area that it became more of a Class 1. 1 material, which occurs around 10μm.

Recommendations:

Due to the poor quality of loads which were employed in this test series, other researchers are encouraged to verify (or hopefully refute) the sensitivity of the formulation TE-E7007.

It was theorized, that due to the presence of dicyandiamide (DCDA) a precursor of nitroguanidine (NQ, a known burn rate suppresser) that the formulation TE-E7007 would have a good chance of passing cook-off tests. However, due to the impact sensitive nature of TE-E7007, cook-off sensitivity tests were not conducted. Other researchers are encouraged to conduct large-scale cook-off tests in order to either verify or refute this theory.

If cook-off insensitivity is validated, but large-scale impact test results are still unacceptable, it may be possible to modify TE-E7007 (by reducing EDDN and/or RDX particle size/content) to the point where desired impact insensitivity results are achieved.

Seventeen micron AP was originally chosen to permit a higher peak pressure by ensuring that sufficient oxygen was immediately available to combusting aluminum. A reformulation of TE-7007 should consider employment of 200μm AP rather than 17μm AP.

Acknowledgments

Gratitude is expressed to Thiokol Corp. and the U.S. Government who funded this research, development, scale-up and advanced testing and who authorized publication of this information. This scale-up effort was conducted at the Huntsville Division of Thiokol Corp. where the author was employed as the Principal Investigator until closure of that facility.

References

1) Sumrall, T.S., "Development of an Economical High Performance Melt Castable Insensitive High Explosive", Journal of Japan Explosive Society, 58, 2, (1997).
2) Sumrall et. al., US Patent No. 5411615, (5/295).
3) Sumrall, T.S., "Arena Test Performance Results of an Economical Melt Castable Insensitive High Explosive Candidate", Propellants Pyrotechnics and Explosives, Accepted for Publication (1/30/97)
4) Burgess, W. P.; "Report of Vulnerability and Performance Tests of ABF Candidate Explosives" (U); Explosion Dynamics Branch, NSWC, Dahlgren, VA; (July 1990).
5) MIL-STD-2105B, Hazard Assessment Tests (12 Jan 1994).
6) James, H.R., TTCP WAG-11 Bullet/Fragment Protocol, AWE (Foulness), UK, (1992).
7) Dobratz, Brigitta M., LA-9732, "Ethylenediamine Dinitrate and its Eutectic Mixtures (A Historical Review of the Literature to 1982)", Los Alamos National Laboratory, NM (May 1993)
8) Akst, I.B., "Nonideal Explosives Research", Idos Corp. Report AFATL-TRE-7995 (1979).
9) Akst, I.B., "Detonation in Intermolecular Explosives: Characeristics of Some Eutectic Formulations", Proc. 7th International Symposium on Detonation, Annapolis, MD (June 1981)

融解性直填可能な汎用不感性爆薬の大型試料による衝撃感度試験結果について

Theodore S. SUMRALL[*]

アルミニウムを添加した融解性爆薬(TE-E7007)は経済性，汎用性，不感性を有した次期爆薬候補として開発された。そのためには小型試料での感度特性が優れ，原材料と製造のコストが低く，理論的には高性能であることが必要であり，さらに大型試料において衝撃感度が低く，経済性と環境の観点から再融解性を有し，またクックオフ中には吸熱反応の特性を有していることが必要である。大型試料による評価試験結果から理論的に予測されていた性能が確認され，続いて大型試料による衝撃感度特性を求めるための試験が行われた。本研究は，TE-E7007爆薬についての大型試料による衝撃感度試験結果(銃撃による衝撃，破片による衝撃，それに殉爆による爆轟)について示す。すべての場合において爆発あるいは爆轟することが分かった。これらの結果により，安全限界の観点からTE-E7007は不採用と見做され，試験費用を節約する観点からクックオフ試験には供さないこととなった。

([*]Advanced Technologies and Studies Department, Sverdrup Technology, Inc., 214
Goverment Street, Niceville, Florida 32578, U. S. A.)