# Development of an economical high performance melt castable insensitive high explosive

by Theodore S. SUMRALL*

A less sensitive high explosive is obtained by using a Dicyandiamide (DCDA), Ammonium Nitrate (AN), Guanidine Nitrate (GN), Ethylene Diamine Dinitrate (EDDN) eutectic melt binder in combination with Ammonium Perchlorate (AP) oxidizer, fine RDX (2 – 10 ㎜ particle size) and aluminum metal. The eutectic binder offers a melt castable, energetic matrix similar to TNT but with improved thermal response. The fine RDX particles improve performance, boosterability and sensitivity. The inclusion of AP greatly improves air blast by adding oxygen to the reaction and aiding combustion of the ingredients. The aluminum extends the pressure pulse. The ratio of eutectic salts is formulated to obtain the lowest known processing temperature. The composition was formulated in hopes of meeting performance, cost and sensitivity goals related to the next generation of U.S. explosives.

## Introduction:

Much effort has been expended in the Research and Development of explosives that have a benign response to stimuli yet meet the performance goals associated with high explosives for military application. A number of the formulations proposed to date have included exotic ingredients which are either too expensive or are not commercially available to meet immediate and near-term production requirements or have required the employment of mixing equipment not traditionally employed for explosive processing. Additionally, with the current emphasis on demilitarization coupled with increased restrictions on the employment of organic solvents, it was determined that it would be very desirable that the formulation be water soluble so that the ordnance could be easily demilitarized and the explosive ingredients recovered and recycled with ease.

Since General Purpose (GP) bombs constitute the overwhelming majority of explosives currently in the United States (U.S.) Department of Defense (DoD) inventory, this research was geared to the formulation of an explosive for GP bomb fill with the following goals:

1. Explosive employs readily available and inexpensive raw materials.
2. Explosive is melt castable and can be manufactured in existing steam kettle equipment, is compatible with current inventory bomb design (MK-80 series) and is boosterable with standard fuse design.
3. Explosive has performance comparable to PBXN-109 (16% inert binder/20%Al/64%RDX)
4. Explosive meets IM criteria per DoD Standard 2105-B
5. Explosive is water soluble and easily demilitarized.

Current GP bombs are filled with meltable TNT based explosives such Tritonal (80% TNT/20%Al) or H-6 (30%TNT/45%RDX/20%Al/5%D-2 Wax) from steam kettle type mixers. When the U.S. Navy first decided to introduce PBX-109 into the inventory, considerable investment in Baker-Perkins type mixers was required and in order to avoid additional expense, it was determined that the

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final formulation would require steam kettle processability (Goal #2).

**Theory:**

Dr. Melvin A. Cook's classic American Chemical Society Text, "The Science of High Explosives" describes an explosive based on the reaction of Ammonium Nitrate (AN) with Calcium Cyanamide ($CaCN_2$) to produce Calcium Nitrate (CN) plus ammonia and an unknown "organic substance"[1]. Cook also reported that the addition of a TNT sensitizer resulted in an explosive with critical diameters on the order of 1.25 inches (5㎜). As part of this research, this "organic substance" was chemically analyzed and determined to be a combination of Dicyandiamide (DCDA) and Guanidine Nitrate (GN). The explosive referenced by Dr. Cook appeared to be very thermally stable, as indicated by in-house differential scanning calorimeter (DSC) analysis, because an endothermic reaction occurs, presumably from thermal degradation and ammonia liberation. It was conjectured that these properties could result in an explosive with cook-off insensitivity, a mandatory requirement of the DoD's IM requirements.

Eutectics employing DCDA, AN and GN (DAG) are discussed in patent literature[2),3)]. DAG eutectic binders were considered ideal candidates from a number of standpoints. First, the raw materials were quite inexpensive (Goal #1). Second, as eutectics are meltable, steam kettle processing was possible (Goal #2). Third, since no hydrocarbon binders would be utilized and because the eutectic binder also contained oxygen, higher densities could be achieved and oxygen would be in close contact to the fuel and could enter into the reaction zone of the CJ Plane, thus improving performance properties (Goal #3). Fourth, based on previous R&D, reduced explosive shock sensitivity was a distinct potential and, based upon the thermal characteristics of GN and DCDA (both precursors of the well known and thermally stable IHE Nitroguanidine [NQ]) it was believed that the thermal response of a eutectic explosive employing GN and DCDA would be very mild (Goal #4). Finally, since AN based explosives are very water soluble, demilitarization goals could be easily achieved (Goal #5).

**Results/Data:**

The lowest melting point (≈ 94 ℃) was demonstrated to be at a DCDA/AN/GN (DAG) ratio of 30/54/16. For maximum safety purposes, the eutectic binder with the lowest melting point was employed. This point was determined based upon seven test data points and the employment of a contour grid plotting program that plotted melting point as a function of three variables. The output of this plotting program provided a very accurate prediction of the lowest possible melting point. However, even after optimization of this tertiary eutectic, it was determined that it would be desirable to employ a eutectic with even lower melting temperatures to alleviate concerns associated with self-heating phenomenon witnessed in large diameter operations where explosive compositions exceed their critical temperature due to the inability of the explosive to dissipate internal thermal energy.

A composition developed by the U.S. Air Force (USAF), identified as AFX-400 consists of a eutectic blend of 46% Ethylenediaminedinitrate (EDDN), 46% AN and 8% Potassium Nitrate (KN)[4)]. This composition had good performance properties but high sensitivity in large diameters, presumably by virtue of the high content of EDDN. The presence of KN retarded the phase change properties of the AN.

It was discovered, however, that addition of between 15−65% EDDN to the DAG eutectic referenced previously, further depressed the melting point of the eutectic. However, it was deemed desirable to limit EDDN content to the lowest possible content to retain insensitivity. After the addition of 15% EDDN, further addition of EDDN did not further suppress the melting point of the eutectic below ≈ 84 ℃. This eutectic binder was designated "DAGE".

In order to decrease the critical diameter of the DAGE eutectic explosives, it was determined that it would be necessary to introduce a small percentage of RDX to permit the final formulation to employ the fuse and booster mechanism in current MK-80 Series GP bombs (Goal #2). Previous research revealed that fine particle size RDX ($< 10\mu$), when introduced into a PBX formulation, was significantly less sensitive than larger particle size RDX. Although RDX is normally not sieved to particle diameters this fine, sufficient material was ground in order to complete the desired R&D. It was determined during the course of this investigation that RDX with a particle range of between $1-4\mu$ gave the lowest sensitivity. However, due to the mechanical limitations of the RDX grinding equipment, only a very limited amount of $<4\mu$ RDX was manufactured. This material verified the marked sensitivity decrease with finer nitramines. However, because there was insufficient $<4\mu$ RDX to load larger size test samples, the remainder of the research was conducted with RDX having an average particle size distribution $\geq 4\mu$.

Aluminum is commonly employed in bomb-fill compositons that have air blast as the primary damage mechanism. The aluminum does not enter into the detonation front but instead burns behind the CJ plane, thus extending a pressure pulse for a longer period of time while decreasing peak pressure. Pressure impulse (the integral of the pressure-time curve) becomes a more important value when attacking typical battlefield targets (i.e. tanks, armored carriers, aircraft etc.) than peak pressure. Peak pressure is of greater importance when attacking hardened targets such as nuclear missile silos. Therefore, aluminum powder was added to the DAGE based eutectic since MK-80 series bombs are normally used against unhardened targets. However, due to addition of the aluminum fuel, oxygen balance calculations revealed that the formulation became oxygen negative. Due to the lower processing temperatures achieved by introduction of EDDN, it was determined that it would be safe enough to introduce Ammonium Perchlorate (AP) into the formulation in order to improve oxygen balance. Addition of AP actually decreased the melting point ≈ 5 ℃.

Very extensive thermochemical calculations of predicted detonation and combustion parameters (velocity, pressure, temperature etc.) were conducted employing thermodynamic codes such as TIGER, BLAKE, and NASA/LEWIS. The predicted effects of ingredient combinations were plotted using a three dimensional statistical evaluation program (which allowed for variation of up to four ingredients at a time) followed by subsequential manufacture and testing of the candidate explosives.

After extensive testing of various formulations, a formula designated as TE-E 7007 was scaled up for advanced testing and comparisons to standard U.S. Navy (USN) compositions, PBX-109 and H-6 (as well as other formulations manufactured by Government and Industry Laboratories) were made. The composition TE-E 7007 had the formulation shown in Table 1.

Table 1 Composition of TE-E 7007 eutectic explosive

| Ingredient | Wt.% |
|---|---|
| DCDA | 10.8 |
| AN | 19.44 |
| GN | 5.76 |
| EDDN | 15.0 |
| AP($17\mu$) | 17.0 |
| RDX($>4\mu$) | 12.0 |

Tests results that justified the scale-up of TE-E 7007 were those required by DoD Explosive Hazard Classification Procedures (TB 700-2) and Ammunition and Explosives Safety Standards (DoD 6055.9-STD).

Screening Tests for IHE are detailed in DoD 6055.9-STD and are listed in Table 2 with the test results associated with TE-E 7007.

Composition TE-E 7007 was therefore scaled up in order to conduct the Expanded Large-Scale Card Gap Test (ELSGT) as well as conduct performance tests (Detonation Velocity and Detonation Pressure) of the composition. Acceptor diameters in typical screening

Table 2 Insensitive high explosive screening tests

| Test Type | Specification | Requirement | Results |
|---|---|---|---|
| Impact | TB 700-2 | <Explosive D | Pass |
| Friction | 6055.9-STD | No Reaction | Pass |
| DTA | 6055.9-STD | 1 st Exotherm<250 C | Pass |
| Small Scale Burn | TB 700-2 | No Detonation or Violent Reaction | Pass |
| Spark Test | 6055.9-STD | >0.25 Joules | Pass |

Table 3 Insensitive high explosive qualification tests

| Test Type | Specification | Requirement | Results |
|---|---|---|---|
| Critical Diameter | JSSPM | N/A | < 2.5 inches Unconfined |
| #8 CAP Test | TB 700 − 2 | No Reaction | Pass |
| Card Gap Test | TB 700 − 2 | > 70 kbars | Pass |

tests are not large enough to give reliable results for the explosives which have large detonation failure diameters. In other words, it is possible that the material has such a large failure diameter that the true sensitivity of the composition is masked. Therefore, the ELSGT was designed in order to test explosives with large failure diameters[5]. The ELSGT is essentially is a factor of 2 scale up of the Naval Ordnance Lab (NOL) Card Gap Test. The dimensions of the ELSGT test specimen are 73.152 mm diameter × 279.4 mm length. Typically, as the diameter of non-ideal explosives increases so does the card gap diameter. However, this does not necessarily translate to increased sensitivity since the booster size employed on the ELSGT is much larger, therefore, transmitted pressure values need to be used rather than card gap values. TE-E 7007 exhibited similar sensitivity (approximately 70 kbars) for both the NOL and ELS Gap Tests. TE-E 7007 had an NOL Card Gap shock sensitivity of + 77 / − 75 kbars (+ 56 / − 60 cards) and an ELSGT sensitivity of + 57 / − 70 kbars (+ 116 / − 169 cards).

Those tests which could be conducted on site are detailed in Table 3 along with the results. Additional IHE Qualification Tests are detailed in DoD 6055.9-STD. Those tests referenced in DoD 6055.9-STD which are not listed in Table 3 were conducted at NSWC/Dahlgren and will be reported in a subsequent paper.

Based on the above test results, a number of 8 inch × 16 inch warheads were loaded to determine the performance of composition TE-E 7007. The units were tested to determine average fragment velocities and peak pressures relative to H-6, PBX-109, Tritonal and seven other bombfill candidates under development by U.S. Government and Industry Laboratories. Additionally, impact sensitivity testing (Sympathetic Detonation, Fragment Impact and Bullet Impact) was performed on TE-E 7007. A detailed report on these test results will be published in a subsequent paper, however, average peak pressures and average positive impulse values compared very favorably with PBX-109 and was superior to Tritonal and all seven of the candidate IHE formulations tested with regards to performance characteristics.

Conclusions:

Four of the five goals (1, 2, 3 and 5) of this project were met as of the date of original publication. The test setup and results of impact sensitivity testing (as well as the set-up of performance testing and more detailed results) will be reported in subsequent papers owing to publication size limitations.

Note:

This paper was originally presented at the 1992 IM Technology Symposium held in Williamsburg, Maryland, in June of 1992. Additional information, originally considered proprietary, has been included in this paper since a patent has been issued on this technology. (U.S. Patent No. 5411615, 2 May 1995). The opinions/recommendations made in this paper are those of the author's and not necessarily those of any other organization or agency.

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# 経済性を考慮した高性能で融解性直填可能な不感性爆薬の研究

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ジシアンジアミド(DCDA)，硝酸アンモニウム(AN)，グアニジンナイトレイト(GN)，エチレンジアミンジナイトレイト(EDDN)などを融解性バインダと過塩素酸アンモニウム(AP)酸化剤，微粒RDX(2～10μm粒径)，金属アルミニウムとを混合することによって感度の低い高性能爆薬を得ることができる。融解性バインダにはTNTと同様な融解して直填できる高エネルギ・マトリックス剤としての役割が要求されるが，熱反応性を改良する特性を有している。微粒なRDXは性能向上と起爆性および感度を改良する。APを添加することは酸化剤として反応を促進させ，燃料成分の燃焼性を向上させることから衝撃圧を増加させることになる。アルミニウムは圧力パルスの作用を増加させる効果を有している。融解性塩類は製造工程における温度を低下させるために添加される。本研究で得られた組成は米国における次世代爆薬の性能，経済性，感度などの要求を満足できるものである。

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