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Investigation of the Physical and Explosives Properties of the Eutectic Explosive Ammonium Nitrate/Ammonium 3,5-Dinitro-1,2,4-Triazolate

1978 Annual Report

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GLOSSARY

ADNT - ammonium 3,5-dinitro-1,2,4-triazolate
Al - aluminum
Amatol - AN/TNT
AN - ammonium nitrate
Composition B, Grade A - 64/36 wt ratio RDX/TNT with 1% wax
Composition B-3 - 60/40 wt ratio RDX/TNT, particle size RDX smaller than in Grade A no wax (used by DOE)
DAT - 3,5-diamino-1,2,4-triazole
EA - 50/50 wt ratio EDD/AN
EDD - ethylenediamine dinitrate
HMX - 1,3,5,7-tetranitro-1,3,5,7-tetrazacyclooctane
KN - potassium nitrate
NQ - nitroguanidine
PBX 9404 - plastic-bonded HMX
RDX - 1,3,5-trinitro-1,3,5-triazine
TATB - 1,3,5-triamino-2,4,6-trinitrobenzene
TNT - 2,4,6-trinitrotoluene

INVESTIGATION OF THE PHYSICAL AND EXPLOSIVES PROPERTIES OF THE EUTECTIC EXPLOSIVE AMMONIUM NITRATE/AMMONIUM 3,5-DINITRO-1,2,4-TRIAZOLATE

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ABSTRACT

Cosolidification of an explosive salt, ammonium 3,5-dinitro-1,2,4-triazolate (ADNT), with an oxidizer, ammonium nitrate (AN), by cooling from the eutectic melt produced a mixture that detonated ideally. The melt was also a good matrix for slurrying other explosives or aluminum. The addition of aluminum to a mixture with excess AN improved the performance. We found that although temperature cycling of cylindrical charges caused 11-vol% expansion, the charges retained their integrity. This report explains the preparation of ADNT and the procedure used to mix AN/ADNT. We determined the explosive sensitivity and performance of AN/ADNT mixtures and their mixtures with other explosives, and we studied particle size and shape by scanning electron microscopy.

I. INTRODUCTION

In the FY 1977 annual report,[1] we showed that at near-eutectic composition, solidified melts of ammonium nitrate (AN) and ammonium 3,5-dinitro-1,2,4-triazolate (ADNT) performed ideally; that is, they detonated at rates predicted by the Becker-Kistiakowsky-Wilson (BKW) hydrodynamic computer code.[2] This was the first time that AN had been shown to release its energy in a thin enough detonation zone to have a detonation velocity within 5% of the ideal. In addition, the plate dents from AN/ADNT eutectic systems combined with RDX or HMX were deeper than expected, as determined from a correlation of plate dents with the Chapman-Jouguet (CJ) pressure of standard explosives.[3] Such results may indicate an explosive with a broadened pressure pulse. A similar pressure profile was calculated at Lawrence Livermore National Laboratory (LLNL) by expanding the length of the detonation zone. As the zone length increases, the peak changes from a sharp spike at zones less than 0.1 μs to one with perceivable width but undiminished height at 0.5 to 2 μs; at times greater than 2 μs, the peak broadens and decreases in height. In the last case, performance is nonideal[4] because a portion of the energy is not contributing to the peak's height or to the detonation velocity. The broadened pressure pulse associated with a 0.5- to 2-μs detonation zone might be better for denting metal than is the sharp spike of the ideal monomolecular explosives.

To use all the power for metal pushing in composite explosives containing nonexplosive oxidizers, the detonation reaction must be complete within a zone of less than 2 μs. One method of achieving this reduces the particles enough to allow complete mixing of the two reacting components within that time. Finger et al.[5] found that 5-μm particulate oxidizers in gelled nitromethane reacted completely, and their 2.54- and 5.08-cm-diam cylinder tests scaled; however, mixtures containing larger particles (for example, 200 μm) failed to scale in cylinder tests. The smallest AN particle obtainable was 9 μm, which came close to scaling. The oxidizers tested at 5 and 200 μm were ammonium and potassium perchlorates.[4,5]

Another method to determine the particle size of oxidizers necessary for complete reaction between the components of composite explosives was used by McGuire, Ornellas, and Akst at LLNL,[6] who found complete randomization of atoms in the detonation products in an ideal monomolecular explosive. Subsequently, they used ^{15}N-labeled AN to make Amatol (AN/TNT) and analyzed its detonation products with a mass spectrometer to determine the amount of nitrogen gas formed with one atom from AN and one from TNT. Only 12% of the nitrogen formed was mixed isotopically, indicating that the diffusion layer of the AN particle was 0.6 μm. Therefore, AN particles must have diameters of 1.2 μm or less before Amatol will detonate ideally.

From the above two experiments, we concluded that ideal performance depends on the particle size of the oxidizer and that the upper limit of the diameter is between 1 and 10 μm. C. L. Mader of Los Alamos National Laboratory determined from calculations that the diameter of oxidizer particles reacting in the detonation zone also depends on the detonation temperature.[7]

To obtain the small particle size and intimate mixing necessary for ideal performance, we chose cosolidification by freezing the eutectic of the oxidizer and explosive salt. The system under study, AN/ADNT, has a eutectic melting point low enough for casting and performs almost as well as Compostion B, Grade A, in 0.025-m-diam sizes.

This report discusses our continuing investigation of the performance of AN/ADNT-containing mixtures and their physical properties and preparations.

II. PERFORMANCE

During 1978, we emphasized performance testing of AN/ADNT, also known as Fairy Dust, and its mixtures with other explosives or additives used to modify the sensitivity, brisance, energy, or melting temperature. The CO_2-balanced, 2/1 molar ratio AN/ADNT received extensive performance characterization this year; Table I gives values for the detonation velocity (D) and CJ pressure (P_{CJ}) from rate stick/plate dent tests. We had eliminated the failure problem observed in the 1.27-cm-diam unconfined plate dent.[1] This material must have pressed to a uniform mixture because little variation in D occurred along the 2.54-cm segments (±1 m/s). The BKW calculation was about 5% higher than the experimental values for D and P_{CJ}, but that is within the error of the calculative method. The scaling of D from unconfined tests supports the idea that the mixture is ideal. The unconfined rate stick and cylinder tests (Table II) have a difference in D of only 2 m/s. These facts show the reproducibility of the processing and demonstrate predictable performance for a near-eutectic composite explosive containing AN. Besides predictability, AN/ADNT can push metal (Gurney energy, see Table II) only 7% less than can Composition B, Grade A, even though the latter has a 5% higher density and contains 60% RDX. The energy release was prompt, resembling the wall velocity curve of PBX 9404 more than that of Composition B, Grade A, with the acceleration of the wall almost zero by the time the expansion had reached the 19-mm point. Therefore, a continuation of acceleration of the cylinder wall, a nonideal behavior usually observed for AN-containing explosives, was not observed.

In the previous annual report, the performance of eutectic AN/ADNT plus 54% RDX was described.[1] Program monitors from the Naval Surface Weapons Center and Navy Sea Systems Command suggested studying a formulation containing less RDX and more AN to decrease costs. We prepared a 5/1/1 molar ratio AN/ADNT/RDX with a CO_2-oxygen balance, but because we did not want to heat the material to above 130°C, not all the AN was dissolved. Some AN particles were too large to react completely in the detonation zone. The results of the 2.54-cm rate stick/plate dent test confirmed the nonideality of the mixture (Table III).

The size of the oxidizer particle that will react in the detonation zone depends on the detonation temperature.[7] The addition of aluminum, which increases detonation temperature, should also increase the ideality of the detonation. This is indeed the case, as shown in Table III, where the aluminized formulation is closer to the calculated performance.

Existing Department of Defense loading plants could use insensitive high explosives (IHEs) if an easily castable IHE were available. We prepared a castable TATB/AN/ADNT formulation containing 50 wt% TATB. Its measured performance can be calculated by averaging the values obtained using RDX and TNT

TABLE I. AN/ADNT (2/1 Molar) Performance Data

Test	Density (g/cm^3)	P_{CJ} (GPa)	D (m/s)
1.27-cm plate dent	1.590	25.2	---
BKW	1.590	25.4	---
1.27-cm plate dent	1.645	23.2 (failing)	---
BKW	1.645	27.6	---
2.54-cm plate dent	1.638	26.1	7892 ± 1
BKW	1.640	27.3	8268
2.54-cm cylinder	1.638	---	7890 ± 3

TABLE II. Cylinder Test Data (2.54-cm diam)

Material	Wall Velocity (mm/μs)		Gurney Velocity (mm/μs)	Gurney Energy (Kcal/g)
	6 mm	19 mm		
2/1 AN/ADNT $\rho = 1.638$ g/cm^3 D = 7.890 mm/μs	1.37	1.53	2.60	0.807
Comp B, Grade A $\rho = 1.714$ g/cm^3 D = 7.911 mm/μs	1.43	1.63	2.70	0.870
PBX 9404 $\rho = 1.847$ g/cm^3 D = 8.787 mm/μs	1.60	1.79	2.88	0.992
2/1 AN/ADNT as % Comp B	95.8	93.9	96.3	92.8
2/1 AN/ADNT as % PBX 9404	85.6	85.5	90.2	81.4

parameters in the BKW code (Table IV). Note that its performance is very close to Composition B (detonation velocity of 7850 m/s), but the impact and thermal sensitivities are much lower: the Type 12 impact sensitivity is 252 cm, compared with 60 cm for Composition B, and the Henkin critical temperature is 239°C, compared with 215°C for Composition B.

Another IHE, NQ, is more economical but less thermally stable that TATB. We found that the thermal stability of NQ is increased by slurrying it in an AN/ADNT melt, resulting in critical temperatures higher than those of either component.[1] Another problem with NQ is its normal habit of crystallization, with long, thin, hollow crystals of low-bulk density. Only a small weight per cent of NQ can be slurried into TNT without the mixture becoming too viscous to cast. However, the AN/ADNT melt dissolves about 12 wt% NQ at 120°C (15-lb steam) so more NQ can be added. The dissolved NQ crystallizes on cooling into long needle crystals that reinforce the structure of the eutectic, resulting in an unusually tough solid. If specially recrystallized, high-bulk-density NQ is used, mixtures with greater than 50% NQ can be cast. The material performs as expected with no degradation in failure diameter of the AN/ADNT.

TABLE III. Effect of Aluminum on A Nonideal Fairy Dust Formulation

	5/1/1 Molar AN/ADNT/RDX	5/1/1/3.3 Molar AN/ADNT/RDX/Al
Sensitivity		
Impact sensitivity		
Type 12 (cm)	43.5	38.4
Type 12B (cm)	73.7	55.3
Henkin critical temp (°C)	219	221
Performance		
Density (g/cm^3)	1.699	1.752
2.54-cm plate dent, P_{CJ} (GPa)	24.0	25.0
Rate stick, D (m/s)	7712 ± 1	7739 ± 10
Calculated P_{CJ} (GPa)	30.4	29.1
Calculated D (m/s)	8598	8223
Ideal P_{CJ} (%)	78.9	86.0
Ideal D (%)	89.7	94.1
Calculated T (K)	1805	3097

TABLE IV. Properties of AN/ADNT Mixtures

	3/1/1 Molar AN/ADNT/EDD	2/1/1.3 Molar AN/ADNT/TATB
Sensitivity		
Impact sensitivity		
Type 12 (cm)	134	252
Type 12B (cm)	153	269
Henkin critical temp (°C)	214	239
Performance		
Density (g/cm^3)	1.607	1.765
2.54-cm plate dent, P_{CJ} (GPa)	24.2	28.3
2.54-cm rate stick, D (m/s)	7664	7845
BKW calculated P_{CJ} (GPa)	27.4	29.3 (RDX), 26.8 (TNT)
Calculated D (m/s)	8287	8307 (RDX), 7720 (TNT)
KSM[8] calculated P_{CJ} (GPa)	25.4	27.8
Calculated D (m/s)	7817	7970
Density (g/cm^3)	1.652	1.765

More specific performance data will be in the FY 1979 annual report.

One disadvantage of the AN/ADNT eutectic is its greater than 110°C melting temperature. However, the temperature may be lowered by adding another component to the eutectic. The first compound we synthesized for this purpose was the N-methyl derivative of dinitrotriazole, prepared by treating the silver salt of dinitrotriazole with methyl iodide.[9] Its mixture with AN/ADNT had a melting point of 88°C, and the Type 12 sensitivity to impact was 48 cm. The major reason for discontinuing investigation of the N-methyl derivative is that EDD reduces the temperature as effectively and more economically. Although an exact ternary composition and temperature have not been determined, differential thermal analysis produced an endotherm with a minimum between 87 and 95°C, depending on the composition. A rate stick/plate dent test was fired, consisting of a mixture with a 3/1/1 molar ratio or 40/29/31 wt ratio AN/ADNT/EDD, a composition midway between CO and CO_2 balanced. The data in Table IV show that the detonation pressure deduced from plate dent was 88% and the detonation velocity was 92.5% of those values calculated by the BKW code.

EDD effectively lowers the AN/ADNT melting temperature because it also forms a low melting eutectic with AN at about a 49/51 wt ratio EDD/AN (EA). We have had difficulties with EA because of its failure to sustain detonation in small-scale-diameter tests without heavy confinement and with densities greater than 96% theoretical maximum density (TMD). However, Akst[10] has reported that adding as little as 16 wt% ADNT enabled the EA to sustain detonation at 97.5% TMD in a confined 2.54-cm test (Table V). In addition, we found that detonation is sustained in an unconfined 2.54-cm-diam cylindrical charge with the addition of only 11 wt% ADNT at a density of 92.4% TMD (Table V). The charge has only 90% of the BKW-calculated detonation pressure at this size, but without ADNT, EA would have failed.[10] The reduced failure diameter indicates that adding ADNT moves the EA system toward ideality. Akst showed that replacing 15 wt% of the AN by KN does not greatly affect performance.[10] The KN modifies the phase transitions of AN by forming a solid solution, but no phase change occurs between -15 to 115°C because AN stays in Phase III, which has a density of 1.667 g/cm³ (Ref. 11). Additional work will be done with mixtures containing KN.

In summary, performance of the eutectic explosive AN/ADNT continues to stimulate interest in using a eutectic explosive as an explosive fill. We have demonstrated that an explosive fuel may be combined with an oxidizer to form a mixture that performs with as much brisance as an ideal monomolecular explosive.

III. EXPLOSIVES PROPERTIES TESTS

A. Particle Size Analysis

We have developed an analytical method to determine the particle size of AN in eutectic mixtures. As discussed

TABLE V. Properties of Mixtures with EDD

	3/0.3/1 Molar AN/ADNT/EDD	2.64/0.47/1/0.37 Molar AN/ADNT/EDD/KN
Sensitivity		
Impact sensitivity		
Type 12 (cm)	58	---
Type 12B (cm)	96	---
Henkin critical temp (°C)	227	---
Performance		
Density (g/cm³)	1.535 (92.4% TMD)	1.626
P_{CJ} from plate dent (GPa) (2.54-cm unconfined)	20.8	25.5 (confined)[10]
BKW calculation		
Density (g/cm³)	1.535	1.626
P_{CJ} (GPa)	23.0	28.2
D (m/s)	7870	8340
T (K)	1475	2179
Gamma	3.14	3.01

in the Introduction. the particle size of the oxidizer in an explosive mixture determines how much of the oxidizer reacts in the detonation zone. The commonly used methods for particle size measurement require separation of the components or measurement before mixing. In our mixture, separation is impossible and the melting process destroys the original dimensions. Therefore, we needed a nondestructive method that would discriminate between components. Akst reported scanning electron microscope (SEM) photographs of EA taken at Los Alamos when he was at Picatinny Arsenal, but he was uncertain which component was AN.[12] Our first photographs of AN/ADNT were similar. We confirmed that the electron-beam-sensitive common component was AN by taking SEM photographs of each component separately. Because the AN particles have a distinctive appearance, their average size can be measured.

The eutectic formulation of AN/ADNT has an AN particle size about three times smaller than formulations 10% rich in AN or 10% rich in ADNT. Also, when a 2/1 molar ratio AN/ADNT was cooled slowly, large 50- to 100-μm crystals of AN were formed (see Figs. 1 and 2; darker areas are AN).

This analytical method can be used for quality control of prepared charges.

B. Impact Sensitivity

The Eastern Research Laboratory-type impact machine equipped with Type 12 tools and a microphone for sound analysis was used to determine the impact sensitivity of the samples. In this test, a 2.5-kg weight is dropped on an anvil in contact with a 40-mg sample on sandpaper. (No sandpaper is used for Type 12B.) A certain sound level indicates a GO. A 50/50 GO/NO GO point is determined by the Bruceton Up and Down method with statistical analysis.[13]

Most materials containing ADNT have moderate sensitivity in the Type 12 test, between 40 cm (those with RDX) and 100 cm (those with small amounts of insensitive explosives). Large amounts of TATB decrease the impact sensitivity even more (Table VI).

C. Critical Temperature

The thermal sensitivity of new materials is measured by the modified Henkin method as developed by Rogers[14] and J. L. Janney, Los Alamos National Laboratory, Group M-1. A thin slab of explosive is confined in a cartridge and timed until explosion in a temperature-controlled bath of Wood's metal. The temperature at which it no longer explodes is the critical temperature (Table VI).

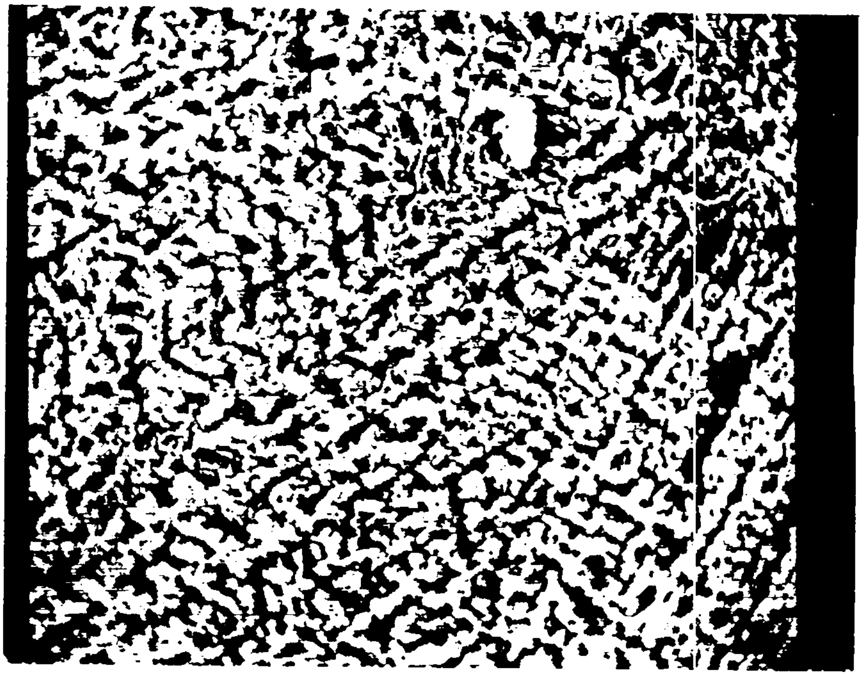
D. Temperature Cycling

One problem of AN-containing explosives is their irreversible growth during temperature cycling. AN expands and contracts as it changes from phase to phase, with different densities. Amatol begins to crumble after a few cycles. We cycled three 1.27- x 1.27-cm cylindrical pellets of 2/1 molar ratio AN/ADNT pressed to a density of 1.64 g/cm^3. To study only one phase change at a time, the first seven cycles were from −54 to 50°C. There was a 6.5-vol% growth, with most growth occurring in the first cycle.

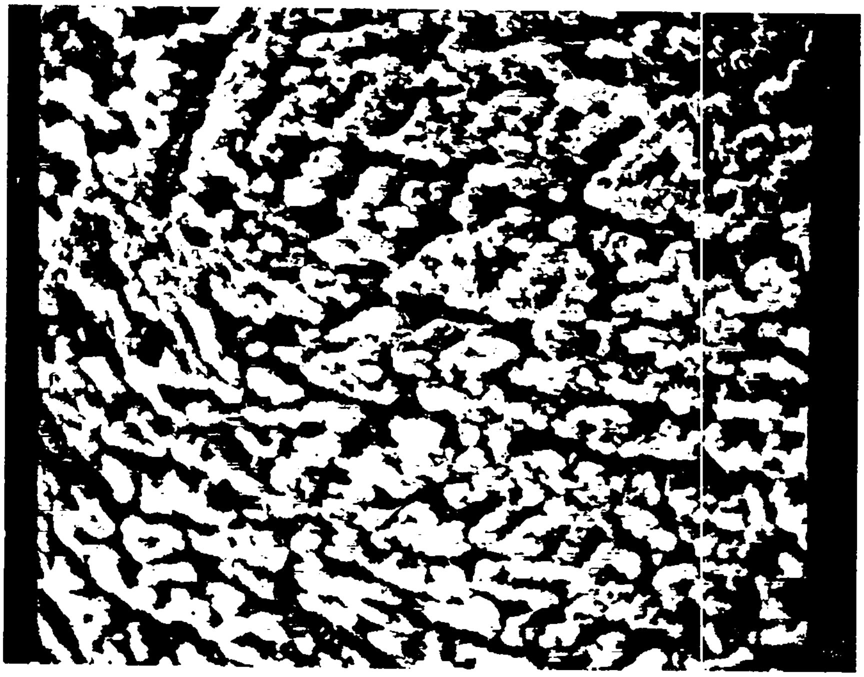
Then we cycled the next 30 days with one cycle per day through the complete military range, −54 to 74°C. An additional 4.4-vol% growth occurred and, again, the major growth was during the first cycle as we brought the system through the phase change at 54°C. Growth during the last 15 cycles was insignificant. The total growth was 10.9 vol%, with no cracking of the pellets. We plan to repeat the temperature-cycling study with 15% AN replaced by KN because, according to the AN/KN phase diagram, AN(IV) is not thermodynamically stable when mixed with that amount of KN; therefore, AN stays in Phase III from −15 to 115°C. Below −15°C it will change to Phase V, but the density difference between Phases III (1.667 g/m^3) and V (1.701 g/cm^3) is not as large as between Phases III and IV (1.725 g/cm^3).

IV. PREPARATION AND ISOLATION OF ADNT

During the last year, our preparation of ADNT was based on a Soviet method.[15] Because the sulfuric acid concentration was not reported, we have optimized the yield by varying the acid concentration. We continued to use 3,5-diamino-1,2,4-triazole (DAT) obtained from Aldrich Chemical Company as starting material, but we plan to optimize the complete synthesis from the more economical cyanoguanidine (dicyandiamide) and hydrazine. Following are a sample synthesis and isolation of ADNT.

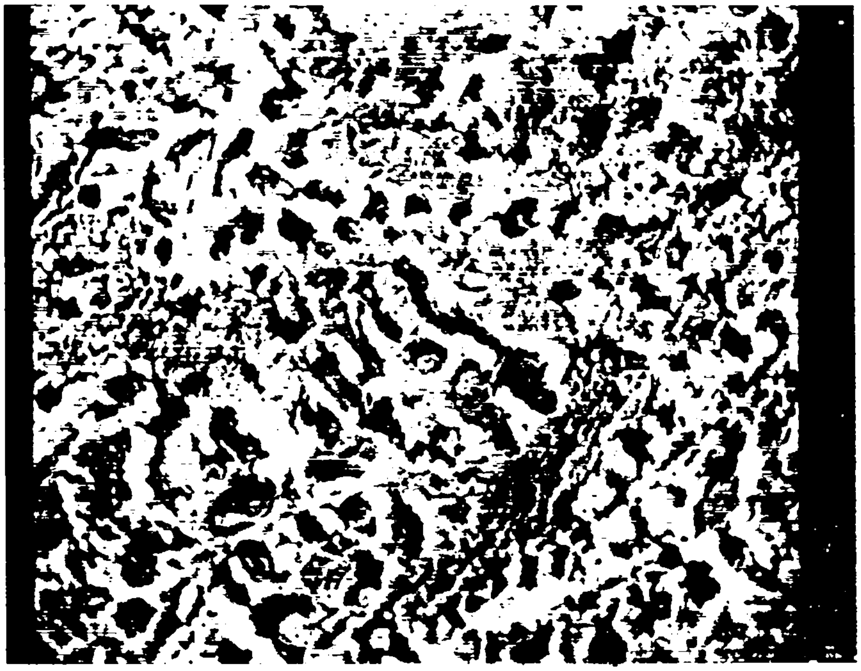


a. 1.38/1 molar ratio AN/ADNT (eutectic) 1000 x

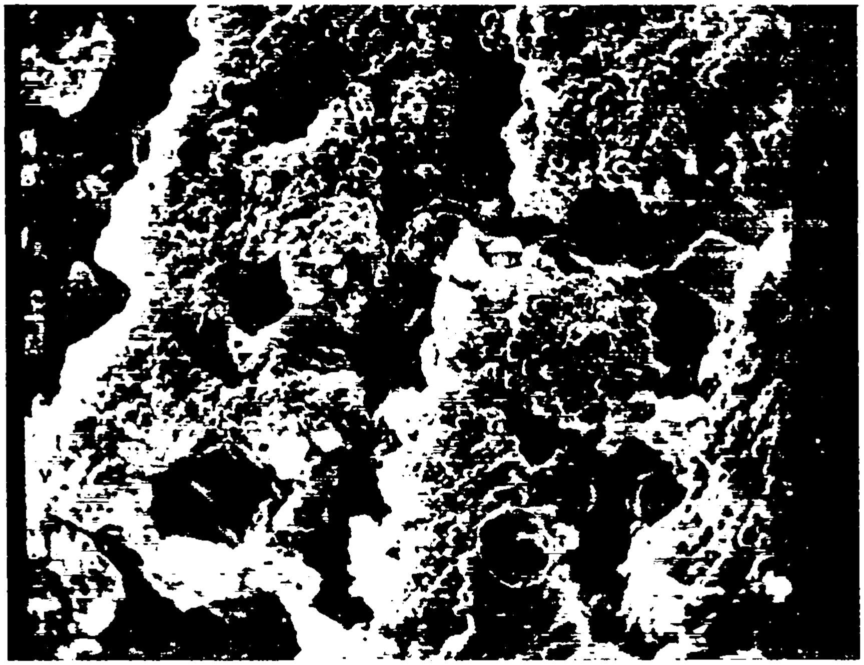


b. 1.5/1 molar ratio AN/ADNT 1000 x

Fig. 1. SEM photographs of AN/ADNT.



a. 1.25/1 molar ratio AN/ADNT 1000 x



b. 2/1 molar ratio AN/ADNT (cooled slowly) 1000 x

Fig. 2. SEM photographs of AN/ADNT.

TABLE VI. Sensitivity Tests

Material (molar ratios)	Impact Sensitivity Type 12 (cm)	 Type 12B (cm)	Critical Temp Henkin (°C)
ADNT	58	96	225
AN	>320	>320	361
1.38/1 AN/ADNT	66	71	236
2/1 AN/ADNT	65	65	241
2/1/1.3 AN/ADNT/TATB	250	270	236
1.38/1/1.54 AN/ADNT/RDX	37	70	215
5/1/1 AN/ADNT/RDX	44	74	219
5/1/1/3.3 AN/ADNT/RDX/Al	38	55	221
EDD	88	115	245
2.33/1 AN/EDD	109	153	244
3/1/1 AN/ADNT/EDD	134	153	214
3/0.3/1 AN/ADNT/EDD	58	96	227
2.55/0.3/1/0.36 AN/ADNT/EDD/KN	74	76	226

A DAT solution (30.0 g, 0.3 mol) in 0.68 M sulfuric acid (1100 mℓ, 1.5 mol H^+) was added dropwise over 3 h to a solution of sodium nitrite (200 g, 2.9 mol) in water (200 mℓ) while keeping the reaction mixture at 0°C with an alcohol-ice bath. After addition was complete, the reaction mixture was heated to 60°C and held for 1 h until all precipitate had dissolved. Then the reaction mixture was cooled again to 0°C and acidified with 6 M sulfuric acid (100 mℓ, 1.2 mol H^+). This step converted the excess sodium nitrite to nitrous acid. Urea (15 g, 0.25 mol) was added slowly (foaming) to remove any remaining oxides of nitrogen from solution. The completed reaction mixture had a small amount of orange precipitate that was removed by adding decolorizing carbon and filtrating. Analysis of the filtrate by ultraviolet spectroscopy at 285 nm showed 90% yield of DNT.

The strongly acidic character of DNT (–0.66 pKa[16]) makes extraction with the usual organic solvents difficult. It can be extracted by ethyl ether, but ether's flammability necessitates another method for large-scale reactions. We found that DNT can be extracted from the aqueous reaction mixture by a toluene solution of water-insoluble secondary or tertiary amines. The amines formed a water-insoluble salt of DNT that was soluble in the toluene phase, removing the DNT from the water and sodium salts. Ammonia gas bubbled into the organic phase regenerates the amine and precipitates the desired ammonium salt, ADNT. Dissolution of the precipitate in 90/10 volume ratio ethyl acetate/acetone separated the ADNT from ammonium sulfate and unidentified orange impurities. Removing most of the solvent by rotary evaporation under reduced pressure precipitated ADNT (35 g, 0.2 mol, 67% yield). The yield may be improved by a second extraction of the aqueous reaction mixture. The amines used were tertiary amines, Alamines 304 and 336 (General Mill Chemicals, Inc.), and a secondary amine, Amberlite (Rohm and Haas Co.). They were used as 20-vol% solutions in toluene and in a 1/1 molar ratio to the amount of DNT in the aqueous solution as measured by ultraviolet spectroscopy.

This extraction method is economical because the amines can be reused after washing in water with only a small percentage loss in extraction power. Also, most solvents can be recovered.

To prepare AN/ADNT mixtures, we used reagent grade AN and recrystallized ADNT, which had been dried overnight in a vacuum desiccator over Drierite. We found that water, besides affecting the weight, lowered the melting temperature. The melting temperature of the eutectic formulation, 1.38/1 molar ratio AN/ADNT, is 112°C.[1] To prepare up to 10 g of the eutectic mixture, 38.5/61.5 weight ratio AN/ADNT, the correct weight of each component was mixed in a 30-mℓ beaker, and the mixture was heated in an oil bath until a uniform melt formed. The oil bath temperature was kept below 125°C.

The melt was cooled quickly by pouring it onto a Teflon surface and spreading it with a spatula. For larger amounts, the components were melted in a 250-mℓ beaker two-thirds submerged in an aluminum block heater. The temperatures of the block and the beaker contents were measured by thermocouples. The mixture was stirred slowly with a Teflon paddle-stirrer driven by an air motor. If a 2/1 molar ratio AN/ADNT mixture is to be prepared, the additional AN is added after melting the eutectic amount of AN/ADNT. To achieve a uniform melt, the mixture was heated to 121°C, which is the liquidus temperature for this mixture according to the phase diagram in Ref. 1. The temperature necessary to bring all the AN or ADNT into solution at any composition can be determined from the phase diagram.

Sometimes it is desirable to add other explosives, KN, or aluminum to the molten mixture and dissolve or slurry them until the mixture is uniform. The beaker contents were poured onto a Teflon sheet and spread thin to cool quickly and to make the solid easy to break into a molding powder for pressing. Uniform charges were pressed under vacuum at 60°C. Before AN/ADNT can be cast uniformly, the problem of bubble formation in the eutectic melt must be solved. Less bubbling occurred in the 2/1 molar ratio melt and in slurry mixtures than in the eutectic mix. This bubbling is caused by a small amount of ammonia gas from ADNT decomposition into ammonia plus DNT. Probably the eutectic mixture can only be pressed. Adding another material to form a ternary eutectic will lower the temperature of the melt and stabilize it. Adding EDD to form a melt with a temperature below 100°C appears to stabilize the melt. Therefore, a practical castable system may be one that contains four or five components, each modifying the properties of the explosive in the melt and in the solid to achieve the physical and explosives properties desired.

V. CONCLUSIONS AND FUTURE WORK

We have found that adding ADNT to AN, which forms a eutectic, makes AN an ideal explosive. Our physical tests and performance tests show that at near-eutectic composition AN/ADNT is hard with fine grain structure, is castable with 15-lb steam temperature, and has predictable detonation velocity and pressure in small-diameter tests. It also is compatible with IHEs, regular explosives, and aluminum.

Because the ADNT used in our experimental work is not available commercially, we made it from purchased starting materials. Therefore, it is expensive and its main use has been to prove that eutectics formed with AN can release energy fast enough for military applications. We will continue the small-scale testing of ADNT-related eutectics systems to fully characterize AN performance controlled by eutectic systems.

We also will test commercially available materials that can easily be made into explosive salts and may form eutectics with AN, but may not have as small a failure diameter. However, because of the ADNT groundwork, fewer performance tests at large diameters will be necessary to evaluate new materials. ADNT still will be a useful experimental explosive because of its small-failure diameter and its close to CO_2-oxygen balance. We are studying its preparation from hydrazine and cyanoguanidine to produce it economically enough to share with other experimentalists. Perhaps at some time there will be a demand for it in munitions. We do not fully understand how tailoring the explosive to produce different shaped isentropes affects munition performance, either fragmenting or underwater.

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