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25 Sept 77

UCID-17376

Lawrence Livermore Laboratory

SAFE EXPLOSIVES FOR SHAPED CHARGES

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January 21, 1977

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Prepared for U.S. Energy Research & Development Administration under contract No. W-7405-Eng-48.

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SAFE EXPLOSIVES FOR SHAPED CHARGES

ABSTRACT

We have demonstrated that high-performance shaped charges could be developed using as the explosive charge mixtures of ingredients that are not, by themselves, considered explosives. At least one of the ingredients needed to be a liquid, stored separately, that could be quickly injected into the shaped charge cavity to generate the active explosive. We obtained precision copper shaped charge cones in diameters of 65.2, 83.8, and 100.2 mm (about 2.6, 3.3, and 4.0 in.), and we had appropriate hardware fabricated. We demonstrated that 4 cone diameters of penetration were obtained in 255 BHN armor plate steel if the explosive charge was nitromethane or a combination of fine crystalline ammonium nitrate at a density of 1.0 Mg/m^3 with nitromethane. However, when prilled ammonium nitrate was used with nitromethane, the jet failed to form.

INTRODUCTION

Unlike some of the newer nuclear weapons in stockpile, older systems have no built-in disabling or destruct mechanisms. Numerous degrees of denial could be considered in case of imminent enemy threat to nuclear weapons storage locations outside the continental United States. One of these is total destruction by detonating the high explosive (HE) in the warhead. This can be accomplished by firing a shaped charge, mounted on the weapon or carrying case, aimed at the warhead's main HE charge.

At present, the shaped charges used for this application have low voltage initiators and are somewhat susceptible to stray electrical signals. Therefore, the shaped charges are not stored mounted on the weapons for fear of unintentional initiation due to these stray signals. Currently, it would take from one-half to two hours to mount and arm the charges and blow the magazine.

We were asked by W Division to demonstrate the feasibility of developing a safe shaped charge using nonexplosive materials that could be rapidly combined remotely to form an explosive mixture directly in the shaped charge. Thus, the shaped charge could always remain mounted in the operating position. The shaped charge was to be capable of penetrating eight inches of mild steel.

HARDWARE

Performance of shaped charges is highly dependent on the cone material, design, and precision. We did not want to spend time and effort developing a shaped charge, so we contacted Picatinny Arsenal. They contributed twelve each of three sizes of precision shaped charge cones. These were all copper cones with a 42° cone angle and a thickness of 1.5% of cone diameter; the sizes were 65.2, 83.8, and 100.2 mm in diameter.

We used stock brass tubing for the container and set the length so that there was a one-cone-diameter explosive head above the virtual apex of the cone. The top closure was solid brass with vacuum and fill ports, a booster cavity that would accept either 12.7-mm-diam or 25.4-mm-diam boosters, and a detonator holder and alignment fixture that would assure axial alignment of the detonator bridgewire and cone apex within 0.51 mm.

Solenoid valves were attached to the two ports to allow remote evacuation and subsequent transfer of the liquid phase. A large graduated cylinder contained the liquid so that the volume transferred to the shaped charge cavity could be measured.

PVC pipe was used to generate a three-cone-diameter (CD) standoff. The target plates were 44.5-mm-thick, 255 BHN armor plate cut to 152-mm (6-in.) squares for the larger charges and 102 mm (4-in.) squares for the smaller ones. Figure 1 depicts the assembly and setup.

EXPLOSIVE INGREDIENTS

Numerous fuel-oxidizer systems were available for consideration. We chose nitromethane (NM) as one of the fuels for several reasons:

- It carried significant oxygen with it, reducing the required density of the oxidizer to a level where it would be permeable.
- It can be detonated by itself but is very difficult to initiate and is classified as a flammable solvent.

Fig. 1. Shaped charge test setup.

- It is stable, well characterized, commercially available, and inexpensive.
- Using NM allowed us to try the neat material or a sensitized NM.

We also decided to examine OTTO* fuel. This alternate fuel was developed for the propellants industry and is also quite stable and well characterized.

The most obvious choice of oxidizers included ammonium perchlorate (AP), potassium perchlorate (KP), and ammonium nitrate (AN). We chose ammonium nitrate because it is relatively easy to work with, was readily available, and has less available oxygen than either of the others. The desire for less available oxygen from an oxidizer may seem unusual, but this comes from the decision to use NM which carries a significant amount of oxygen internally. With large amounts of available oxygen from the oxidizer, the mixture would be above CO_2 balance at very low densities of oxidizers. A near optimum mixture for oxygen balance would be AN at 1.0 Mg/m^3 with the voids filled with a 50/50 mixture of NM and OTTO fuel. See Appendix A for a further discussion.

PRELIMINARY PERFORMANCE TESTS

Prior to firing any shaped charge tests, we needed to test several initiation and detonation parameters of the proposed system. They were:

- Permeability of the 1.0- or 1.1-Mg/m^3 -density AN by the fuel mixtures.
- Detonability and performance of the mixtures.
- Qualities of the booster HE needed to reliably initiate the mixture through a 0.25-mm brass barrier.
- Possible use of prilled AN. (AN is available in free-flowing beads 1 to 2 mm in diameter known as prills. Each bead is at about 94% of the theoretical maximum density, TMD, and the bulk density of the prills is about 0.75 Mg/m^3 .)

The most convenient way to examine these parameters is with our plate dent test. The test uses a 76-mm-diam $\times$ 76-mm-long copper cylinder as a witness plate. A 25.4-mm-diam $\times$ 25.4-mm-long test explosive cylinder is

* OTTO fuel is 1,2-propyleneglycoldinitrate/di-n-butylsebacate/2-nitrodiphenylamine - 76.0%/22.5%/1.5% by weight.

centered on one face of the plate and confined by a 12.7-mm-thick copper cylinder 38.1 mm high (Fig. 2). We can investigate various initiation schemes fairly easily with this setup. Performance is easy to characterize on a gross scale by measuring the depth of the dent in the witness plate.

The conclusions we drew from these tests are as follows:

- We had to use vacuum loading techniques to achieve complete permeation of the liquid fuel into pressed pellets of AN at densities of 0.9, 1.0, and 1.1 Mg/m³.
- Mixtures using OTTO fuel did not develop high order detonation.
- LX-10 booster pellets 25.4 mm in diameter, were required to reliably initiate neat NM, or NM with prilled AN, through 0.43-mm-thick brass.
- LX-10 booster pellets 12.7 mm in diameter, adequately initiated mixtures of NM with 6- μ m AN through the brass barrier.
- With adequate initiation, neat NM or any combination of NM and AN detonated and produced essentially the same depth of dent in the witness plate.

Appendix B contains the details of the plate dent tests.

PENETRATION TESTS

Three sets of penetration tests were fired. The first set used neat NM with 25.4-mm-diam $\times$ 12.7-mm-long LX-10 boosters. The second set used prilled AN at 0.75 Mg/m³ with NM filling the rest of the volume; the larger booster pellets were also used in this case. The final set used predried, 6- μ m AN directly loaded to density into the shaped charge. NM again filled the remainder of the volume. In the last set, 12.7-mm-diam $\times$ 12.7-mm-long LX-10 booster pellets were used. In all cases, the NM was remotely loaded into shaped charge cases by evacuating the case and then opening it to atmospheric pressure transfer.

The results of these tests are given in Table 1.

Fig. 2. Plate dent test.

Table 1. Results of shaped charge penetration tests.

Charge diameter (mm)	Ammonium nitrate		Penetration	
	Type	Density (Mg/m ³)	(mm)	CD
65.2		None	267+	4.1+
83.8		None	260	3.1
100.2		None	400+	4.0+
65.2	Prilled	0.75	Not fired	
83.8	Prilled	0.75	~12	~0
100.2	Prilled	0.75	~12	~0
65.2	6 μ m	1.10	61	0.9
65.2	6 μ m	1.10	175	2.7
83.8	6 μ m	1.10	109	1.3
83.8	6 μ m	1.00	330	3.9

DISCUSSION

Our estimates of the maximum probable penetration were based on some work by Simon and DePersio.¹ Assuming all other conditions to be equal, the penetration capability of a shaped charge bears a linear relationship to the Chapman-Jouget pressure (P_{CJ}) of the explosive when P_{CJ} is estimated by $P_{CJ} = 0.25 \rho D^2 \times 10^{-6}$ where

D = the detonation velocity of the explosive in m/s,

ρ = the explosive density in Mg/m³, and

P_{CJ} = the detonation pressure of the explosive in GPa (1 GPa = 10 kbar).

1. J. Simon and R. DePersio, *The Evaluation of the Effect of Explosive Filler on Shaped Charge Performance and Lethality Effectiveness*, Ballistic Research Laboratories; Rept. BRL 1552 (1971) (C).

Using the five explosives* from the report by Simon and DePersio having P_{CJ} from 31.5 to 19.4 GPa, we derive the following:

$$\text{Penetration (CD)} = 0.045 P_{CJ} + 3.611.$$

This is based on using the BRL 83.8-mm precision-shaped charge with a 2-CD standoff and 280 BHN armor plate targets. The correlation coefficient for the fit is 0.97. Extrapolation from their lowest pressure explosive, Amatex 40, to 11.3 GPa for NM, predicts a penetration of 4.1 CD. This is consistent with the two shots that penetrated the complete stack of target plates and continued into the gravel below. A limit to this extrapolation is necessary since the equation predicts a penetration of 3.611 CD with a P_{CJ} (detonation velocity) of zero.

Performance of a shaped charge is highly dependent on the quality of the hardware, particularly the cone, and the homogeneity of the high explosive. We believe that the shots using prilled AN failed to form a jet because of the inhomogeneity of the explosive. The 1- to 2-mm beads of AN, with the remaining volume filled with NM, generated two distinct pressure regions on a fine scale. This caused nonuniform pressures and jumpoff velocities in the copper cone. The resulting instabilities prevented the jet from forming, although the explosive did detonate.

We believe that a similar explanation describes the reason for low results when we pressloaded the 6- μ m AN into the shaped charge at 1.1 Mg/m³. Nonuniformity of density in the AN would account for pressure variations in the explosive and instabilities in the jet formation. The final shot, with 6- μ m AN pressloaded to 1.0 Mg/m³, demonstrates that this technique can be made to work properly. However, since it is not really any better than neat NM, there may be no advantage to working out fabrication techniques that would assure uniform density.

CONCLUSIONS

A shaped charge capable of high performance can be made using materials not classified as explosives, and it can be remotely armed and fired in just

* PBXW-110, Octol (70/30), Composition B, Pentolite, and Amatex 40.

a few minutes. If the larger boosters required to initiate the neat NM are objectionable, the NM can be sensitized and made susceptible to initiation by the smaller booster pellets. Since the initial requirement for penetration of eight inches of steel seems extreme, future work should concentrate on developing smaller shaped charges.

APPENDIX A: SELECTION OF REACTANT MATERIALS

When discussing oxygen balance of explosives, we can make a reasonable approximation using the following rules:

- All hydrogen forms water, which is the most favorable reaction.
- The next most favorable reaction is to form carbon monoxide. If there is not enough oxygen for all the available carbon, the system is under CO balance.
- Any additional oxygen will form CO₂.
- Oxygen above a CO₂ balance is wasted.

An extremely general consideration is that an oxygen balance halfway between CO and CO₂ (50% CO₂ balance) will give nearly optimum performance.

The oxygen balance of fuels under consideration is

NM $2(\text{CH}_3\text{NO}_2) \rightarrow 3\text{H}_2\text{O} + \text{CO} + \text{C} + \text{N}_2$ (50% CO balance), and

OTTO fuel — complex structure (15.3% CO balance).

Oxygen is available from potential oxiders as follows:

Potassium perchlorate, $\text{KClO}_4 \rightarrow \text{KCl} + 2\text{O}_2$,

Ammonium perchlorate, $\text{NH}_4\text{ClO}_4 \rightarrow 2\text{H}_2\text{O} + \text{O}_2 + 1/2 \text{N}_2 + 1/2 \text{Cl}_2$,

Ammonium nitrate, $\text{NH}_4\text{NO}_3 \rightarrow 2\text{H}_2\text{O} + 1/2 \text{O}_2 + \text{N}_2$.

AN has significantly less available oxygen than either of the others. We calculated the oxygen balance of NM, OTTO fuel, and a 50/50 mixture of the two as a function of the density of the AN. The results are shown in Table A-1. AN at a density of 1.0 Mg/m³ and the 50/50 fuel mixture are near optimum in oxygen balance.

Prior to mixing multigram quantities of the proposed ingredients, we performed preliminary sensitivity tests on small laboratory samples. We ran abbreviated drop hammer tests on ammonium nitrate mixed with NM, OTTO fuel, and the 50/50 mixture of NM and OTTO fuel. Since these were abbreviated tests, we did not try to determine a 50% point. The lowest drop height to create an event (using a 2.5-kg hammer) was 125 cm on the AN-OTTO fuel mix. No events occurred with the other mixtures using a drop height of 177 cm.

The differential scanning calorimeter was used to investigate the compatibility between the materials. We noted an exotherm only when the mixture of AN and OTTO fuel was used. The exotherm started at 170°C, which was above the melting point of AN, and involved liquid kinetics. The endotherms for the phase changes and melting of the AN were observed at their normal temperatures; vaporization of NM (when used) occurred at about 100°C.

Table A-1. Oxygen balance of ammonium nitrate fuel mixtures.^a

AN density (Mg/m ³)	Fuel		
	NM	50/50 mix	OTTO
0.90	76% CO ₂	19% CO ₂	85% CO
0.95	92%	30%	94%
1.00	5% over CO ₂	43%	3% CO ₂
1.05	15%	58	14%
1.10	27%	75%	28%
1.15	41%	95%	43%

^aSystem oxygen balance when we used pressed ammonium nitrate at various densities and filled the interstices with the listed fuel.

APPENDIX B: PLATE DENT TESTS

The following tables list the plate dent tests made in the preliminary evaluations.

Table B-1. Variations in 6- μ m AN density and fuel (dent in mm).^a

AN density (Mg/m ³)	Poured in		Fuel		
	NM	OTTO	NM	Vacuum loaded 50/50 mix	OTTO
0.9	8.6	5.6	8.9	7.4	2.3
1.0	8.9	6.6	9.1	5.3	2.8
1.1	8.4	4.8	8.1	3.3	2.0

^aAll shots used 12.7-mm diam $\times$ 12.7-mm-long Tetryl boosters initiating through 0.05-mm Al foil. The initiation system may have been subcritical for the mixtures using OTTO fuel.

Table B-2. Determination of best booster.^a

Booster diameter and length (mm)	Barrier (mm)	Test HE	Dent (mm)
12.7 $\times$ 12.7 Tetryl	0.43 brass	6- μ m AN at 1.0 Mg/m ³ + NM	9.2
12.7 $\times$ 12.7 Tetryl	0.43 brass	6- μ m AN at 1.0 Mg/m ³ + NM	8.5
25.4 $\times$ 12.7 LX-10-0	0.43 brass	Prilled AN + NM	8.7
12.7 $\times$ 12.7 LX-10-0	0.43 brass	Prilled AN + NM	5.3
12.7 $\times$ 12.7 Tetryl	0.05 Al	Neat NM	4.5
12.7 $\times$ 12.7 LX-10-0	0.05 Al	Neat NM	7.5
12.7 $\times$ 12.7 LX-10-0	0.43 brass	Neat NM	7.8
25.4 $\times$ 12.7 LX-10-0	0.43 brass	Neat NM	9.3
25.4 $\times$ 12.7 LX-10-0	0.43 brass	Neat NM	9.3

^aLX-14-0 (HMX/Estane 5702-F1-95-5) will give a dent of 11.9 mm in this test.

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Available from
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