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Transition
FFTN and HMX

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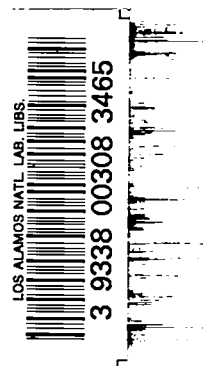
LA-9620

UC-45

Issued: February 1983

The Deflagration-to-Detonation Transition in PETN and HMX

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THE DEFLAGRATION-TO-DETONATION
TRANSITION IN PETN AND HMX

by

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ABSTRACT

The deflagration-to-detonation transition (DDT) can be made to occur in both PETN and HMX. The reaction is sensitive to the degree of subdivision and the compactness of the explosive in which the transition takes place. It apparently happens better with explosives of small specific surface loaded at low density.

Experiments using thin metal shims between the donor and transition-explosive charges suggest that transition-explosive compression makes an important contribution to the DDT process.

I. INTRODUCTION

Secondary explosives such as PETN,* HMX,** and RDX*** can be ignited by a hot wire at low current and low voltage. The threshold ignition levels as a function of explosive specific surface at several loading densities have been reported.¹ If the confinement of the ignited explosive is restrictive enough and other criteria are met, the deflagration will build up (transit) into a detonation. This reaction--the deflagration-to-detonation transition (DDT)--has been investigated by many in the past three or four decades. Recently we have reported some observations of the DDT reaction in PETN and HMX under a variety of assembly conditions.^{1,2} This report includes the results of varying the

*Pentaerythritol tetranitrate ($C_5H_8N_4O_{12}$).

**1,3,5,7-tetranitro-1,3,5,7-tetrazacyclooctane ($C_4H_8N_8O_8$).

***1,3,5-trinitro-1,3,5-triazacyclohexane ($C_3H_6N_6O_6$).

explosive specific surface and loading density in the transition zone as well as testing the confinement of the donor reaction.

II. EXPERIMENTAL DETAILS

The test fixture was the ER-322 assembly, shown in Fig. 1. The bridgewire material is Nichrome V (80% nickel + 20% chromium) that is 0.05 mm in diameter and resistance-welded between Fe/Ni alloy electrodes 2.4 mm apart. The electrodes are embedded in a compressed-glass header. The donor explosive is loaded into a Lexan charge holder that is 4.4 mm in diameter and 4.0 mm long. The transition barrel is made in two sections; the sections are loaded separately and then screwed together to form the cylindrical cavity. This approach minimizes variation in the pressing density caused by loading and permits easy adjustment of the transition charge dimensions. Each section of the transition barrel has a 2.5-mm inner diameter and is 7.0 mm in length. The overall length of the barrel is 14 mm, which is significantly longer than the shortest explosive charge length found to undergo the DDT reaction.²

The specific surfaces (S_o^P) of the PETN and HMX differed. The S_o^P value of the PETN† was varied by changing the rate of mixing water with PETN/acetone solutions. The HMX samples†† were the beta (β) polymorph material, which had been wet-ground to the desired fineness by 2.5-cm-diameter porcelain balls.

†Trojan Powder Company, 17 North 7th, Allentown, PA 18101.

††Holston Defense Corporation, P. O. Box 749, Kingsport, TN 37662.

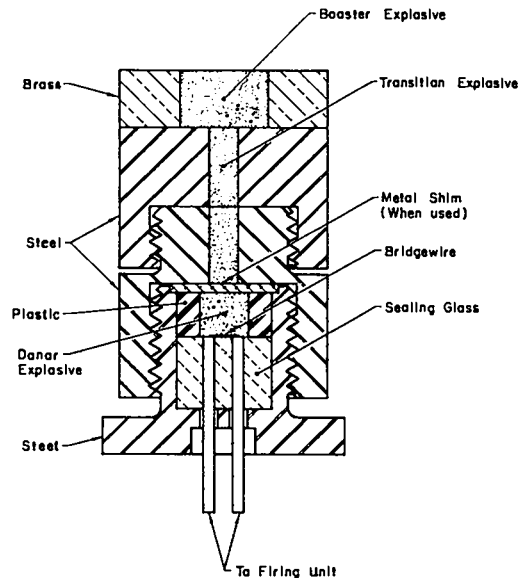


Fig. 1. DDT assembly (ER-322 Type).

The bridgewires were heated rapidly by passing direct current through the circuit from an external source. The voltage used was measured as 5 V; the current was approximately 4 A. The ignition-current threshold of PETN and HMX in these assemblies is less than 1 A.

III. DISCUSSION OF RESULTS

A. PETN

PETN of three widely differing specific surface values ($S_o^P = 3650, 8400,$ and $14,600 \text{ cm}^2/\text{g}$) at $1.0\text{-g}/\text{cm}^3$ loading density was ignited. The DDT took place in each. Dents were produced in 6061-T6 aluminum witness slugs attached to the downstream end of the transition barrels. No consistent variation in dent depth with PETN specific surface change could be found. It appears, however, that the PETN with the smallest S_o^P value (largest "average particle size") produced the deepest dent in the witness slug. Although the density of the PETN sample in the transition zone was varied between 1.0 and $1.4 \text{ g}/\text{cm}^3$, its specific surface was held constant at $3650 \text{ cm}^2/\text{g}$. Dents were again observed in the aluminum witness slugs, showing that the DDT reaction had occurred. Table I gives both sets of data.

TABLE I

DDT IN ALL-PETN ER-322 ASSEMBLIES WITHOUT A BOOSTER PELLET

Donor: PETN		$S_o^P = 3650 \text{ cm}^2/\text{g}$		Density = $1.64 \text{ g}/\text{cm}^3$		Mass = 100 mg
Transition Barrel					6061-T6 Aluminum Witness Block Dent	
PETN S_o^P (cm^2/g)	Mass (mg)	Density (g/cm^3)	Diameter (mm)	Length (mm)	Depth (mm)	
3650	72	1.0	2.5	14.0	0.7	
8400	72	1.0	2.5	14.0	0.5	
14600	72	1.0	2.5	14.0	0.5	
3650	72	1.0	2.5	14.0	0.4	
3650	86	1.2	2.5	14.0	0.8	
3650	100	1.4	2.5	14.0	0.8	

Booster pellets of PBX 9407* material (density = 1.6 g/cm³) were substituted for the witness slugs to see whether the detonation produced in the DDT was strong enough to initiate a high-density secondary-explosive pellet. All systems detonated. The transition-zone PETN that was examined had an S_o^P of 3650 cm²/g and was pressed to 1.0-, 1.2-, and 1.4-g/cm³ density. In these experiments we measured the diameter and the depth of the dent in a 2024 Dural witness block and calculated the estimated cylindrical volume. The data from these shots are given in Table II.

TABLE II
DDT IN ALL-PETN ER-322 ASSEMBLIES WITH A BOOSTER PELLET

Donor: PETN $S_o^P = 3650 \text{ cm}^2/\text{g}$ Density = 1.64 g/cm³ Mass = 100 mg
Booster Pellet: PBX 9407 Density = 1.6 g/cm³ Mass = 376 mg

<u>Transition Barrel</u>					<u>2024 Dural Witness Block Dent</u>		
<u>PETN</u>	<u>Mass</u>	<u>Density</u>	<u>Diameter</u>	<u>Length</u>	<u>Depth</u>	<u>Diameter</u>	<u>Volume</u>
S_o^P (cm ² /g)	(mg)	(g/cm ³)	(mm)	(mm)	(cm)	(cm)	(cm ³)
3650	72	1.0	2.5	14.0	0.28	1.43	0.4
3650	86	1.2	2.5	14.0	0.23	1.41	0.4
3650	100	1.4	2.5	14.0	0.21	1.54	0.4

From the earliest days in hot-wire initiation work, it has been recognized that confinement is crucial.^{1,3} In these systems the downstream end of the donor is only partially confined by metal. Placing a thin metal shim between the donor and transition charge would increase the confinement of the donor reaction, but we didn't know whether this would interfere with, enhance, or show no effect on the behavior of the transition charge. To study this we chose aluminum (6061-T6) and stainless steel (303) shims of various thicknesses. Table III shows the thicknesses of the thin shims that work in all-PETN DDT detonators--0.025- to 0.100-mm aluminum as well as 0.025- and 0.50-mm stainless steel. The shims appear to enhance the transition--at least they do not interfere. This leads us to postulate that their action (1) provides higher pressure through better and longer confinement of the deflagration in the donor and (2) more efficiently compresses the transition explosive in which the DDT reaction takes place.

*94 wt% RDX + 6 wt% EXON 461.

TABLE III

THE EFFECT OF SHIMS ON DDT IN ALL-PETN ER-322 ASSEMBLIES

End-Closing Shim Type/Thickness (mm)	Transition Barrel					2024 Dural Witness Block Dent		
	S_o^P PETN (cm ² /g)	Mass (mg)	Density (g/cm ³)	Diameter (mm)	Length (mm)	Depth (cm)	Diameter (cm)	Volume (cm ³)
Donor: PETN $S_o^P = 3650$ cm ² /g Density = 1.64 g/cm ³ Mass = 100 mg								
Booster Pellet: PETN Density 1.3 g/cm ³ Mass = 306 mg								
6061-T6 Aluminum								
0.025	3650	72	1.0	2.5	14.0	0.24	1.22	0.3
0.050	3650	72	1.0	2.5	14.0	0.20	1.09	0.2
0.100	3650	72	1.0	2.5	14.0	0.21	1.22	0.2
303 Stainless Steel								
0.025	3650	72	1.0	2.5	14.0	0.22	1.19	0.2
6061-T6 Aluminum								
0.025	3650	86	1.2	2.5	14.0	0.23	1.22	0.3
0.050	3650	86	1.2	2.5	14.0	0.24	1.11	0.2
0.075	3650	86	1.2	2.5	14.0	0.18	1.25	0.2
0.100	3650	86	1.2	2.5	14.0	0.19	1.19	0.2
303 Stainless Steel								
0.025	3650	86	1.2	2.5	14.0	0.20	1.25	0.3
0.050	3650	86	1.2	2.5	14.0	0.19	1.25	0.2

There seems to be an upper limit of PETN density (about 1.4 g/cm³) that will undergo the DDT reaction. A density of 1.6 g/cm³ consistently fails to give evidence of detonation.^{1,3} Even though the great majority of these failures were observed in systems without donor end-closing shims, no improvement was noted when the metal shim was inserted in a few experiments. Apparently there is a maximum density that will transit to detonation; this is consistent with the DDT mechanism proposed by Sulimov, one aspect of which is that combustion products penetrate through pores into unreacted explosive, preheating the material and helping initiate a low-velocity detonation.⁴ It is also consistent with the mechanism put forth by Campbell⁵ that adiabatic shear occurring within the crystallites is important, it not determinative. Although the difficulty in obtaining a high degree of dent reproducibility precludes our being certain, an apparent preference of the DDT reaction for that PETN sample having the smallest S_o^P number also agrees with these proposals.

The donor density can be decreased to 1.44 g/cm³ and/or the PETN booster pellet can be replaced by the more standard high-density (1.6-g/cm³) PBX 9407

explosive, and the assemblies will function properly. The dent in the witness block is invariant if the donor density is decreased but increases if the high-density PBX 9407 explosive is used.

HMX can be substituted for PETN in the transition zone of DDT assemblies, but the powder and mechanical prerequisites for the deflagration to build up into a detonation are much stricter. We have found that those transition charges that do build up require (1) HMX powder with both a relatively low S_o^P value (3450 cm²/g) and loading density (1.0 g/cm³ or less) as well as (2) the thinnest of donor-confining aluminum shims. These requirements appear to reflect several properties of HMX as compared with PETN: HMX has a lower shock sensitivity, porosity, and particle-size effect. The data from the experiments carried out in these areas are given in Table IV.

TABLE IV
ADDITIONAL DATA USING PETN AS DONOR EXPLOSIVE IN ER-322
ASSEMBLIES WITH BOOSTER PELLETS

		Donor: PETN		$S_o^P = 3650 \text{ cm}^2/\text{g}$		Density = 1.44 g/cm ³		Mass = 88 mg	
		Booster Pellet: PETN		Density = 1.3 g/cm ³		Mass = 306 mg			
		Transition Barrel				2024 Dural Witness Block Dent			
End-Closing Shim Type/Thickness (mm)	S_o^P (cm ² /g)	Mass (mg)	Density (g/cm ³)	Diameter (mm)	Length (mm)	Depth (cm)	Diameter (cm)	Volume (cm ³)	
6061-T6 Aluminum									
0.025	3650	86	1.2	2.5	14.0	0.18	1.21	0.2	
0.100	3650	86	1.2	2.5	14.0	0.20	1.19	0.2	
303 Stainless Steel									
0.025	3650	86	1.2	2.5	14.0	0.23	1.06	0.2	
0.050	3650	86	1.2	2.5	14.0	0.22	1.10	0.2	
		Donor: PETN		$S_o^P = 3650 \text{ cm}^2/\text{g}$		Density = 1.64 g/cm ³		Mass = 100 mg	
		Booster Pellet: PBX 9407		Density = 1.6 g/cm ³		Mass = 376 mg			
		Transition Barrel				2024 Dural Witness Block Dent			
End-Closing Shim Type/Thickness (mm)	Explosive S_o^P (cm ² /g)	Mass (mg)	Density (g/cm ³)	Diameter (mm)	Length (mm)	Depth (cm)	Diameter (cm)	Volume (cm ³)	
6061-T6 Aluminum									
0.025	PETN: 3650	86	1.2	2.5	14.0	0.26	1.34	0.4	
0.050	PETN: 3650	86	1.2	2.5	14.0	0.24	1.34	0.3	
0.100	PETN: 3650	86	1.2	2.5	14.0	0.24	1.33	0.3	
0.025	HMX: 3450	72	1.0	2.5	14.0	0.25	1.31	0.3	
0.100	HMX: 3450	72	1.0	2.5	14.0		No Dent		

B. HMX

All-HMX hot-wire DDT detonators can be assembled successfully. Again, conditions are more restrictive than in all-PETN systems, apparently because of the less sensitive nature of HMX explosives. The effect of particle size and loading density on the ignition process is visible using HMX as the donor charge, whereas it is relatively unimportant with PETN.¹ Increasing both pressing density and S_o^P value (decreasing "average particle size") permits ignition of HMX using lower firing voltages and currents.

HMX whose S_o^P number was 8300 cm²/g was chosen as the donor charge. The pressing density usually was 1.64 g/cm³. The electrical firing conditions of 5-10 V (4-8 A) were well above the 50% fire/fail values, nominally 1 V/1 A. The downstream end of the donor was confined by 6061-T6 aluminum or 303 stainless steel shims.

In the transition zone, the loading densities tried were 0.8 and 1.0 g/cm³. More compact pressings were eliminated because previous work done in SE-1-N assemblies indicated these would not be initiated.¹ Lower pressing densities of HMX do not hold together. The relatively coarse ($S_o^P = 3450$ cm²/g) sample of HMX was used because the flying plate mode of transition-charge initiation to detonation indicated that 8300-cm²/g material would not initiate a high-density PBX 9407 pellet.

The results are given in Table V. With an HMX transition-charge loading density of 1.0 g/cm³, none of the detonators that ignited produced a dent in a 2024 Dural witness block. A larger diameter transition zone did not help. When PETN was substituted for HMX in the transition zone at 1.0 g/cm³ density, a DDT reaction occurred. The use of PETN as a donor charge gave a dent, evidence that a DDT reaction can be obtained in HMX at a density of 1.0 g/cm³, but not with an HMX donor. The successful all-HMX combinations occurred only at a density of 0.8 g/cm³ without a shim or with 6061-T6 aluminum or 303 stainless steel shims 0.025 mm thick. Thicker shims were not compatible with achievement of a DDT reaction.

TABLE V
EFFECT OF SHIMS ON DDT IN ALL-HMX ER-322 ASSEMBLIES
WITH BOOSTER PELLETS

Donor: HMX $S_o^P = 8300 \text{ cm}^2/\text{g}$ Density = 1.64 g/cm³ Mass = 100 mg
 Booster Pellet: PBX 9407 Density = 1.6 g/cm³ Mass = 376 mg

End-Closing Shim Type/Thickness (mm)	Explosive S_o^P (cm ² /g)	Transition Barrel				2024 Dural Witness Block Dent		
		Mass (mg)	Density (g/cm ³)	Diameter (mm)	Length (mm)	Depth (cm)	Diameter (cm)	Volume (cm ³)
6061-T6 Aluminum								
None	HMX: 3450	58	0.8	2.5	14.0	0.21	---	---
0.025	HMX: 3450	58	0.8	2.5	14.0	0.20	1.46	0.3
0.050	HMX: 3450	58	0.8	2.5	14.0		No Dent	
0.100	HMX: 3450	58	0.8	2.5	14.0		No Dent	
None	HMX: 3450	186	1.0	4.0	14.0		No Dent	
0.025	HMX: 3450	186	1.0	4.0	14.0		No Dent	
0.025	HMX: 3450	72	1.0	2.5	14.0		No Dent	
0.050	HMX: 3450	72	1.0	2.5	14.0		No Dent	
0.100	HMX: 3450	72	1.0	2.5	14.0		No Dent	
0.050	PETN: 3650	72	1.0	2.5	14.0	0.25	1.30	0.3
303 Stainless Steel								
0.025	HMX: 3450	58	0.8	2.5	14.0	0.23	1.33	0.3
0.125	HMX: 3450	58	0.8	2.5	14.0		No Dent	
0.025	HMX: 3450	72	1.0	2.5	14.0		No Dent	

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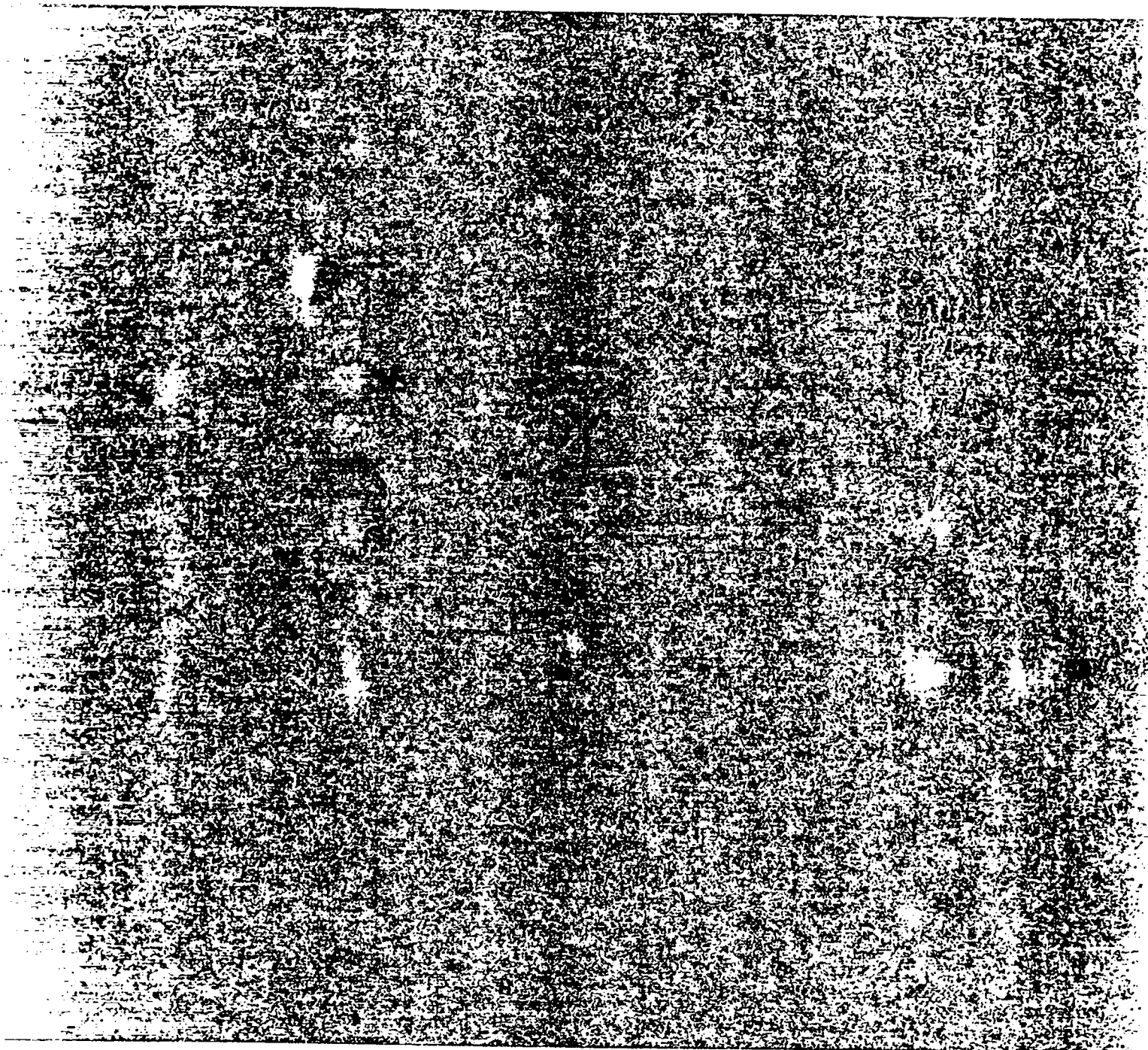
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