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CUSTOMIZED EXPLOSIVES BASED ON PLASTIC-BONDED MIXTURES OF TATB AND HMX

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Experimental data are presented for a series of TATB-HMX mixtures with Kel-F 800 binder. Both detonation properties and safety properties were evaluated.

The addition of HMX to TATB makes possible a wide range in such properties as specific energy, detonation velocity and divergence, failure diameter and handling safety. This flexibility is not without penalty however. The sensitivity of TATB-HMX mixtures increases rapidly with increasing HMX content, even at relatively low levels of HMX and some trade-off must be made between detonation properties and safety.

I. INTRODUCTION

The use of insensitive high explosives such as nitroguanidine (NQ) or triaminotrinitrobenzene (TATB) with more energetic, more sensitive explosives such as hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) or octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX) has made it possible to design explosive formulations with a wide spectrum of properties. This was recognized by a number of investigators developing explosive materials for military applications. In fact, Composition B is an example of combining a relatively insensitive explosive, TNT, with the more energetic, more sensitive explosive, RDX.

Heller, Johnson, and Rosen (1) found that they could not initiate detonation in plastic-bonded NQ formulations even with large 94 wt% HMX/3 wt% nitrocellulose/3 wt% plasticizer (PBX 9404) boosters, and suggested addition of RDX to reduce the size of the booster required. They found that addition of 10 wt% RDX to plastic-bonded NQ had a profound effect on shock sensitivity of the mixture.

The availability of TATB and the potential of developing explosive formulations with a wide spectrum of initiation and detonation characteristics has led us to evaluation of plastic-bonded HMX-TATB formulations. We have investigated formulations with up to 45 wt% HMX, but we have emphasized materials with 5-25 wt% HMX because we wanted to maximize safety characteristics of these formulations. Formulations generally contained 5 wt% Kel-F 800 (copolymer of vinylidine fluoride and chlorotrifluoroethylene) binder. This binder was used in this homologous series so comparisons could be made with the relatively well-characterized explosive PBX 9502 (95/5 wt% TATB Kel-F 800). For practical use a desensitizing binder might well be more desirable.

II. EXPLOSIVE CHARGE PREPARATION

All the plastic-bonded TATB/HMX formulations were prepared using a water slurry process. The polycrystalline explosives were mixed in water to form a suspension, or slurry. A solution of Kel-F 800 plastic dissolved in ethyl acetate was added to the water slurry. The mixture was agitated to prevent segregation and the solvent was removed by a combination of extraction in the water and distillation. The resulting explosive granules, about 1 mm in diameter, were a homogeneous mixture of HMX and TATB crystals coated with plastic. The molding powder was vacuum dried to remove water and solvent.

The HMX used in these formulations was Type II, Class B with a median par ticle diameter of about 15 µm. The TATB had a mean particle diameter of about 60 µm.

Explosive charges were prepared by preheating and compression molding the powder under vacuum (2) to final densities between 97 and 98% of their theoretical maximum densities (TMD). Test specimens were prepared by standard explosives machining techniques.

The formulations described in this work are identified in Table 1.

III. DETONATION VELOCITY AND FAILURE DIAMETER

The detonation velocities of four mixtures of TATB and HMX were experimentally determined as a function of composition and charge diameter. The variations in detonation velocity with reciprocal radius for the different formulations, corrected to 98% of theoretical density (TMD) are presented in Fig. 1. The data are reasonably well fit with straight lines. This is rather surprising, because, although PBX 9502 shows a straight diameter effect curve, the explosive formulations studied here contain significant amounts of HMX. Explosives based on HMX, such as PBX 9404, show diameter-effect curves that are concave downward. We might observe some curvature for those compositions for which the failure radii were not determined (X-0343 and X-0344).

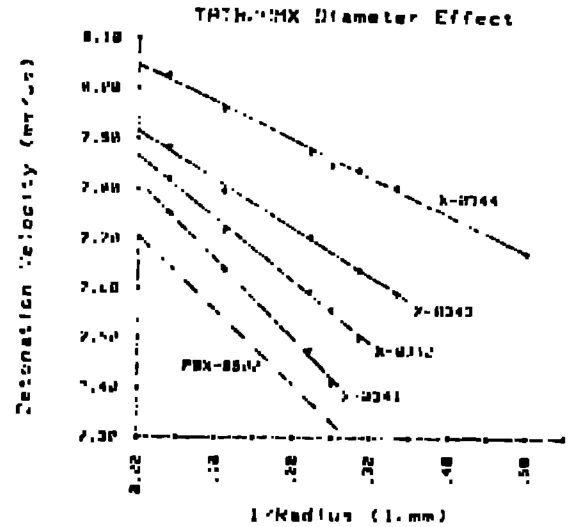

Fig. 1. Detonation Velocities of TATB-HMX Mixtures.

The diameter-effect data were fit with the form $D = D_i - B/r$ where D is the detonation velocity at charge radius r, B is a constant, and D_i is the detonation velocity at infinite diameter. The parameters and the 95% confidence limits obtained from least-squares fit, are presented in Table II.

TABLE I

Compositions of TATB HMX Explosives

Material	TATB %	HMX %	Kel-F 800	Theoretical Max. Density (g/cm³)
PBX 9502	95	0	5	1.942
X-0341	90.25	4.75	5	1.940
X-0342	85.5	9.5	5	1.9[illegible]
X-0343	80.75	14.25	5	1.9[illegible]7
X-0344	71.25	2[illegible].75	5	1.9[illegible]
X-0321	75	20	5	1.934
X-0320	60	[illegible]5	5	1.928
X-03[illegible]	50	45	5	1.9[illegible]
PBX 9501	0	95	5[a]	1.855

[a]Binder is 2.5 wt% Estane, 2.5 wt% nitroplasticizer rather than Kel-F 800.

TABLE II

Detonation Velocity of HMX-TATB Mixtures

Material	Density @ 98% TMD g/cm^3	Infinite Diameter Det Velocity mm/μs	B mm/μs
PBX 9502	1.895	7.706 ± 0.028	1.50 ± 0.20
X-0341	1.901	7.816 ± 0.054	[illegible] ± 0.31
X-0342	1.899	7.866 ± 0.031	1.25 ± 0.16
X-0343	1.898	7.915 ± 0.025	0.97 ± 0.11
X-0344	1.894	8.046 ± 0.018	0.75 ± 0.06
PBX 9501	1.832	8.802 ± 0.015	0.17 ± 0.009

The experimental results for infinite-diameter velocity (adjusted to a uniform density of 1.89 g/cm^3) are compared with values computed for the mixtures using the method proposed by Kamlet and Hurwitz (3) in Fig. 2. The parameters for Kamlet's function were obtained by linear combination of the parameters for TATB and HMX without including any correction for the Kel-F 800. The resulting velocities were then scaled so that the computed value for neat TATB agreed with the experimentally measured value of 7.705 mm/μs for PBX 9502. The two anchor points for the curve are PBX 9502 and PBX 9501.

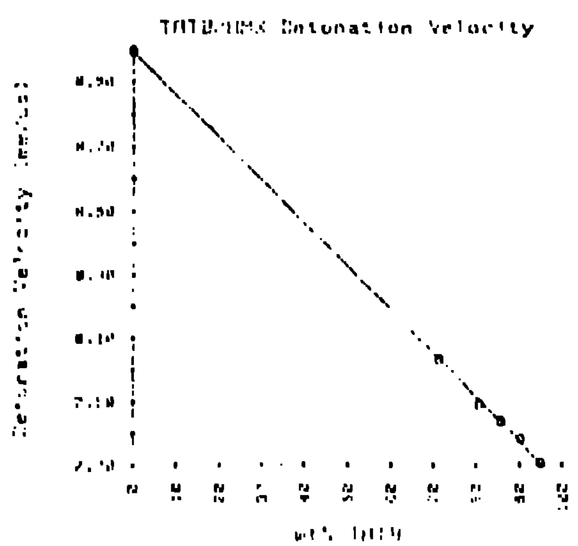

Fig. 2. Infinite Diameter Detonation Velocities of TATB-HMX Mixtures.

The constant B in the fitting form described above should be related to the reaction zone thickness (4,5) in the detonating explosive. We expect B to decrease with increasing HMX content. This relationship is shown in Fig. 3. The curve is nonlinear and there is no statistically significant difference between B for PBX 9502 and for X-0341. This apparent anomaly will be discussed later. The HMX anchor point is PBX 9501, as no comparable data are available for an HMX/fluorocarbon explosive. The other anchor point is PBX 9502.

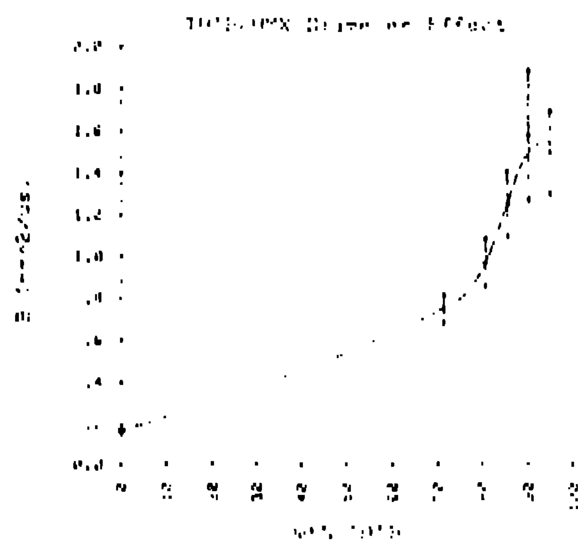

Fig. 3. Diameter Effect Parameter B for TATB-HMX Mixtures.

The failure diameter data we have obtained are summarized in Table III including anchor points of PBX 9502 and PBX 9501. The data are plotted in Fig. 4. Here we note again that we have a nonlinear decrease in failure diameter with increasing HMX content.

TABLE III

Failure Diameter

Material	Failure Diameter Brackets (mm) Detonates	Fails
PBX 9502	9	8
X-0341	8	7
X-0342	7	6
X-0343	6	not determined
X-0344	4	not determined
PBX 9501	2	1

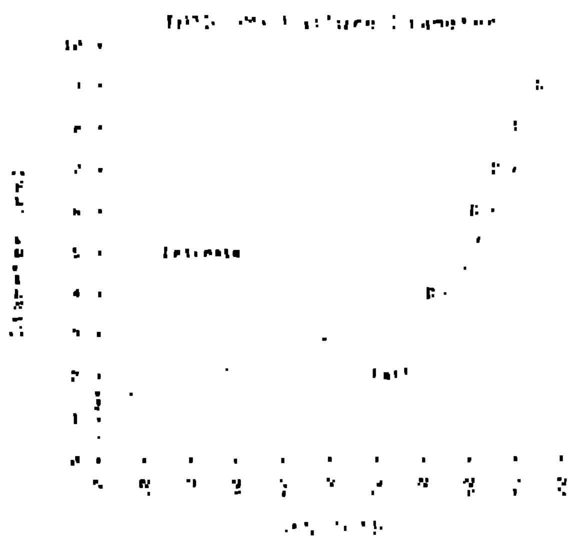

Fig. 4. Failure Diameter of TATB-HMX Mixtures.

IV. SHOCK INITIATION OF DETONATION

In explosive charges subjected to a sustained shock, the distance (or time) to transition from a reactive shock to a steady state detonation is a function of the composition, the density, the particle size, and, to a lesser extent, the initial temperature. We have examined the effect of composition using the wedge test (6) at four pressures - 7, 8, 9, and 11 GPa. Although we do not yet have enough data to define a "Pop Plot," some general trends are apparent.

At the lower pressures the data show that the fractional change (relative to that of PBX 9502) in the distance of run is a nearly linear function of the HMX content up to 15%. A 5-wt% increase in HMX content produces a decrease of 30% in this distance. At 11 GPa, the first 5 wt% of HMX produces no significant effect on the run distance. Additional HMX lowers the run distance about the same as for the lower pressure.

We have obtained more extensive quantitative data in an unconfined 41.3-mm gap test. (7) The data are presented in Fig. 5. There is a significant change in the slope of the curve at about 25 wt% HMX.

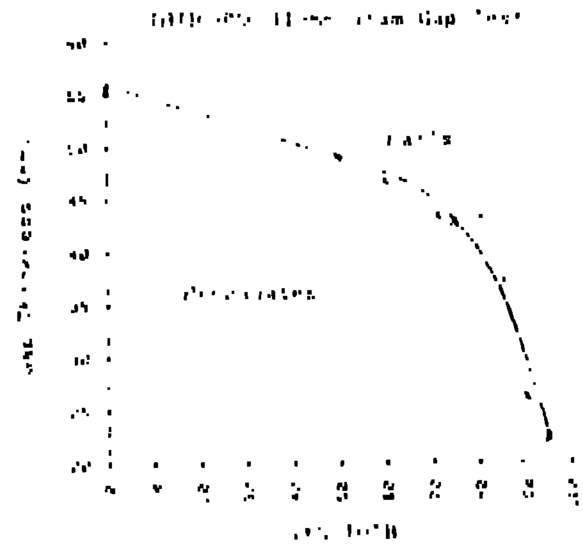

Fig. 5. Large Scale Gap Test Results of TATB-HMX Mixtures.

V. RESPONSE TO ABNORMAL ENVIRONMENTS (IMPACT, FIRE, AND PROJECTILE ATTACK)

It is well known that explosives decompose exothermally at a rate that increases exponentially with temperature. (8-10) If through some mechanical effect or exposure to high temperature a small volume of explosive is heated to a temperature at which the rate of energy generation exceeds the rate of energy dissipation, the reaction grows. The quantitative aspects of initiation and growth to detonation are extremely complex and cannot be accurately predicted with existing theories. For this reason a wide variety of tests are used to obtain an estimate of relative behavior. These tests generally provide a measure of the ease with which initiation will occur and the ease with which the reaction will continue to grow.

Several tests have been conducted with plastic-bonded TATB-HMX mixtures. The results of drop-weight impact tests for plastic-bonded TATB/HMX are given in Fig. 6. Mixtures containing less than 20 wt% HMX do not react at the maximum drop height, 320 cm. The Los Alamos drop-weight impact apparatus is similar to the Bruceton apparatus and uses unconfined test samples. The Type 12 test uses loose powder placed on sandpaper; the Type 12B test uses loose powder on a bare anvil.

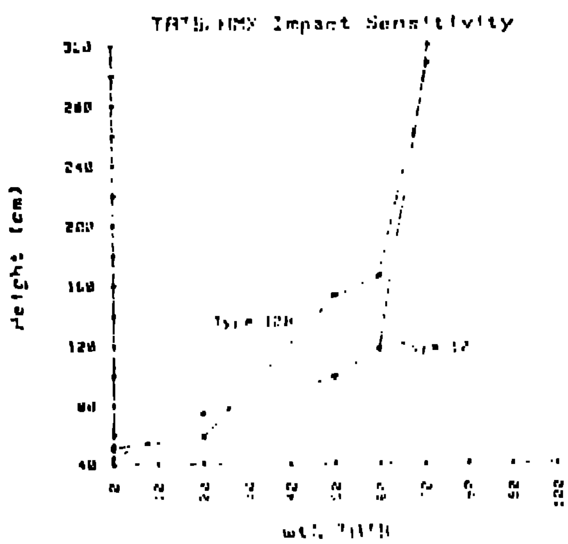

Fig. 6. Drop-Weight Impact Sensitivity of TATB/HMX Mixtures.

A brief series of oblique impact, or skid tests (11,12) was performed. Results obtained in this test are presented in Table IV.

TABLE IV

Skid Test Results[a]

Composition, wt% TATB/HMX/Kel-F 800	Density (g/cm³)	H_{50} (ft)
0/90/10	1.869	[illegible][b]
20/70/10	1.973	[illegible][b]
40/50/10	1.878	~64[b]

[a]Eleven-kilogram hemispherical charge dropped on 80D-grit garnet paper target with a 45° impact angle.

[b]Insufficient tests to statistically determine H_{50}.

In this kind of impact test, mixtures containing as much as 50 wt% HMX appear to be relatively insensitive.

The Lawrence Livermore National Laboratory (LLNL) conducted a series of Susan Tests (13,14) on formulations consisting of TATB-HMX mixtures with various binders. Although the mechanical properties of these explosive formulations should differ from those of the Kel-F bonded materials, the response obtained as a function of increasing HMX content should be indicative of what could be expected in the Kel-F 800 bonded system. In general the LLNL data (15) show low to moderate reactions for all formulations containing less than 50 wt% HMX, even at projectile velocities greater than 400 m/s.

The response of explosives exposed to fire or high temperatures is directly related to the thermal decomposition kinetics. In confined systems exposed to rapid heating, the explosive will generally start decomposition or burning at the outer surface. After some time the burning front will either transit to a detonation or the gas pressure generated by the combustion products will exceed the holding capacity of the case and the case will explode. With gas explosions, the unburned explosive will be scattered about and the case will rupture into large, low-velocity fragments. If the cased explosive is exposed near the critical temperature, the reaction will start in the interior of the explosive. This could, depending upon the size of the charge and degree of confinement, build to a detonation.

Critical temperatures for mixtures of HMX and TATB were determined in the Henkin test. The results are given in Fig. 7. It is interesting to note the distinct break in the curve around 20 wt% HMX.

The response of HMX-TATB Kel-F formulations confined in heavy steel cases and subjected to both rapid and slow heating was determined. (15,16) Results are given in Table V.

This series of heavily confined slow-heating tests is being continued to define the highest level of HMX that results in a pressure rupture. A recent test with X-0419 confined at 100 MPa resulted in a partial detonation at 218°C.

The response of explosives to high-velocity projectile attack is similar to the response expected in the deliberate initiation of detonation

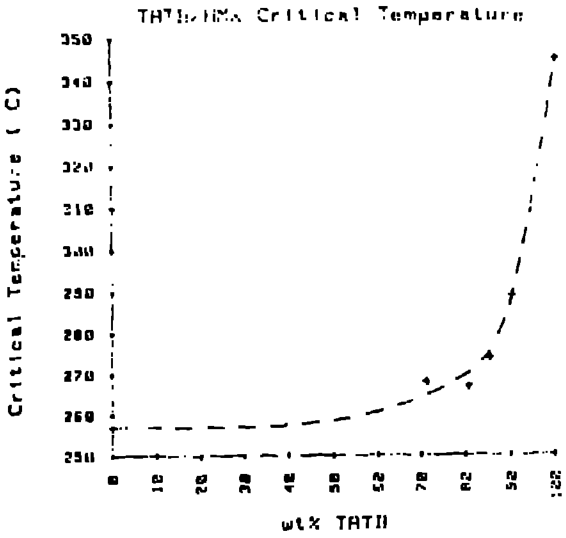

Fig. 7. Henkin Test Critical Temperatures of TATB-HMX Mixtures.

tained exothermic reaction can start. This can terminate as either a gas explosion or detonation.

A series of tests was performed on TATB-HMX mixtures using a standard M-16 rifle and .223-caliber steel-jacketed bullets. The test charges were lightly confined in a plastic fixture. Results of these tests are summarized in Table VI. PBX 9502 does not react in this test. Even in this severe test a mixture containing 20 wt% HMX reacts relatively mildly.

VI. CONCLUSIONS

The addition of HMX to TATB makes possible wide variation in such properties as specific energy, detonation velocity and divergence, failure diameter, shock and thermal sensitivities and handling safety. This flexibility is not without penalty, however. Because PBX 9502 is only about 80% as

TABLE V

Summary of Confined Heating Tests

Composition, wt% (TATB/HMX/Kel-F)	Heating Rate	Rupture Pressure MPa	Temp (°C)	Result
40/50/10	Slow	483	250	Detonation
90/0/10	Slow	483	315	Pressure Rupture
90/0/10	Slow	300	300	" "
90/0/10	Slow	483	213	" "
90/0/10	Fast	551	--	" "
PBX 9404	Slow	483	250	Detonation
PBX 9404	Fast	551	---	Detonation

with a strong shock. As the projectile strikes the case or explosive, a shock is transmitted to the explosive. If the impulse transmitted to the explosive is greater than the critical impulse, detonation will occur after a short-time delay. The critical impulse required to initiate detonation can be reduced if the density of the charge is lowered. This can occur in multiple fragment attack. The first projectile pulverizes the explosive and a second projectile can initiate detonation.

Another type of initiation can also result from projectile attack. If all or part of the projectile remains embedded in the explosive, thermal energy from the hot projectile can be transferred to the explosive and a sus-

energetic as Composition B in the cylinder test, some trade-off must be made between detonation properties and safety.

The nonlinear behavior of some properties with increasing HMX content, when compared with the linear behavior of others, permits some insight into the mechanism of energy contribution within the effective zone of reaction. Properties dependent on the total available energy at high pressure (e.g., detonation velocity) are proportional to the HMX content. We have found that the failure diameter decreases rapidly with the addition of small amounts of HMX until the HMX content approaches 20 wt%. The slopes of the diameter effect curves are also

TABLE VI

Multiple Bullet Impact Tests of TATB-HMX-Kel-F Mixtures Using M-16 (0.223 cal Standard Military Bullets

Shot	Velocity m/s	Material and No. of Shots[1]	Results
1	1024	X-0319 First Shot	No go; projectile did not exit HE
2	1022	X-0319 (from 1)	Full detonation; projectile struck charge 19 mm from first hit
3	1018	X-0319 First shot	Cook-off; charge burned completely, projectile did not exit charge
4	1004	X-0319 6 shots at once	Full detonation; charge went off as 2nd or 3rd bullet was striking
5	1007	X-0320 First shot	No go; projectile exited holder
6	992	X-0320 (from 5) Second shot	Cook-off; charge burned completely
7	1020	X-0320 6 shots at once	Partial reaction; holder broken up and scattered around, wood stand splintered, recovered HE had black burn marks visible
8	1000	X-0320 First shot	Cook-off; charge burned completely, projectile did not exit holder
9	991	X-0321 3 shots at once	Small partial reaction; top half of sample holder and HE blown off
10	1004	X-0321 (from 9) Single shot	No go; bullet did not exit holder. Because top half of charge and holder were blown off in shot 9, charge was unconfined
11	1002	X-0321 2 shots at once	Small partial; top of charge and holder blown off, table splintered
12	1010	X-0321 (from 11) Shot 3 single shot	Small partial; holder broken in small pieces, shot table splintered
13	1021	X-0321 Shot [illegible] single shot	Cook-off; did not smoke or flame for over a minute, charge burned completely. Bullet did not exit holder

[1]Multiple shots are fired at approximately 0.1-s intervals.

fected by the addition of 5 wt% HMX. Shock initiation data show that the addition of 5 wt% HMX causes an increase in sensitivity at low pressure (9 GPa) but not at high pressure (13 GPa). Further addition of HMX results in increased sensitivity in both pressure ranges.

It appears that at lower pressures, the lower concentration of HMX contributes a greater proportion of the effective en[illegible] At higher pressures, where the effective zone of reaction is relatively thin and significant amounts of TATB are reacting, small amounts of HMX do not significantly affect the extent of reaction.

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