LA-UR-93-1119

Conf-930713--6

TITLE: Temperature Effects on Failure Thickness and Deflagration-to-Detonation Transition in PBX 9502 and TATB

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SUBMITTED TO: Tenth International Detonation Symposium

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TEMPERATURE EFFECTS ON FAILURE THICKNESS AND THE DEFLAGRATION-TO-DETONATION TRANSITION IN PBX 9502 AND TATB

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The deflagration-to-detonation (DDT) behavior of TATB has been investigated at high temperatures and severe confinement. Comparison is made to other common explosives under similar confinement. TATB did not DDT under these conditions. The failure thickness of PBX 9502 at 250° C has also been determined. Two mm appears to be the limiting value at this temperature.

INTRODUCTION

PBX 9502 (95/5 wt. % of triaminotrinitrobenzene/Kel-F 800 plastic) is an explosive (HE) that, when examined at room temperature, is much less sensitive to shock initiation than many others. However, studies of its shock initiation behavior at high temperature (greater than 75° C) have begun only recently.

Using cylinders of PBX 9502, Campbell[1] found that the failure diameter is very temperature dependent and that it varied inversely with the temperature when tested at -55°, 24°, and 75° C. He also showed that temperature effects on detonation velocity were functions of the diameter of the explosive. At small diameters, rate effects dominate (and the detonation velocity decreases as the temperature decreases) while at large diameters, density effects dominate (and the detonation velocity increases as the temperature decreases).

Ramsay[2] performed a study in which wedges of PBX 9502 were used to determine the failure thickness at the same temperatures as Campbell.[1] From theoretical considerations, the failure thickness should be one half of the failure diameter. Ramsay's study experimentally demonstrated this result, although the failure thickness was underestimated by 0.5 mm when the wedges were only 50 mm long.

Campbell and Engelke[3] showed that the failure diameter of an explosive increases as the reaction zone thickness increases. They also demonstrated the differences in the mechanism of detonation propagation between large and small diameter charges and between homogeneous and heterogeneous explosives.

Dallman[4] has obtained data showing the effect of temperature on the distance required to achieve detonation as a function of pressure (Pop Plot). He shows that as temperature increases, the Pop Plot curve shifts to the left and the slope increases, indicating a significant increase in shock sensitivity. In fact, the sensitivity of PBX 9502 to shock at 250° C approaches that of PBX 9501 at ambient temperature.

Shocks are not the only mechanism whereby HE may be initiated. Deflagration can also result in detonation under the correct conditions. The ability of many explosives to undergo deflagration-to-detonation transition (DDT) has been evaluated. For example the DDT behavior of ball powders,[5] HMX,[6] Tetryl,[7] and RDX[8] have all been studied. However, the DDT behavior of PBX 9502 has not been previously examined. Sources that can initiate DDT range from either gas-producing or gasless ignitors, to a relatively mild compaction wave originating at a piston or other compressive source. The mechanism by which a reactive wave in an explosive changes from deflagration to detonation is not known precisely, but it has been established to be a function of many variables including confinement, porosity, and reactivity, melting point and combustion velocity.

The results of the studies involving shock initiation at high temperature have obvious implications for the safety of components that incorporate TATB-based explosive. The results of DDT studies on other explosives are not sufficient to predict the response of PBX 9502 to DDT stimulus.

This paper presents measurements of the failure thickness of PBX 9502 at temperatures up to 240° C. We also examined the high temperature DDT behavior of the explosive component of PBX 9502, triaminotrinitrobenzene (TATB), and compare it with several other explosives under varying conditions.

EXPERIMENTAL RESULTS

Deflagration To Detonation Transition In TATB

The purpose of this portion of the study was to determine if, under the most severe conditions of confinement and temperature, TATB powder would undergo DDT. TATB was used instead of PBX 9502 because it is believed that the explosive alone is more sensitive without the addition of the binder. Studies have shown that TATB decomposes at temperatures above 325° C and melts at 450° C, but it is felt by some that some reaction actually begins at temperatures as low as 250° C when the sample is maintained at temperature for extended periods of time. To avoid potential problems with decomposition, we chose a maximum temperature of 250° C. In all, three experiments were conducted, two at 200° C and one at 250° C.

The TATB used in this study was from lot 12-11-81-0503-151 obtained from Group M-1 at Los Alamos National Laboratory. Analysis showed that 50.3% of the particles passed through a 45 μ screen and 30.4% passed through a 20 μ screen. The HE was placed into the tube in small increments and hand-packed lightly with a wooden dowel. The failure diameter of TATB at a density of 1.7 g/cc and ambient temperature is 6.4 mm.[9] The failure diameter at lower densities and higher temperatures is not known, however, based upon experience with other explosives, we believe the tube diameter used in this study to be sufficient to support steady detonation of this material.

In our previous DDT experiments[6] conducted at room temperature, the ignitor system was comprised of a Pyrofuse wire onto which was placed ~20 mg of a stoichiometric mixture of titanium and boron powder followed by varying amounts of Class A HMX powder. However, HMX decomposes and/or detonates at temperatures less than 250° C. Thus HNS (hexanitrostilbene) was used in place of the HMX for the high temperature experiment, with all other elements of the ignitor remaining the same.

The steel confining tube was 127 mm o.d., 25.4 mm i.d., and 305 mm long. A pressure transducer was used to monitor the pressure inside of the tube to indicate the presence of decomposition. No pressure rise occurred before the desired ignition took place.

To examine the effects of confinement, the three tests used tubes that had different types of confinement on the ends. The first experiment used the least confinement and the last experiment used the greatest. The first shot (B-9686) had small endcaps, 1 in. thick, that were secured to the tube with 0.25 in. threaded rod. For the next experiment (B 9688), the endcaps were replaced with large 25.4 mm thick steel plates that were tied together with 0.75 in threaded rod. The bottom plate had small clearance holes through which the Pyrofuse wires were passed. The same configuration was used for the last experiment (B-9712) except that grooves were machined into the bottom plate through which the Pyrofuse leads were passed. This prevented the escaping gas from having clear passage through the clearance holes. The proof and tensile stress of the threaded rod were approximately 55 kpsi and 69 kpsi respectively.

The major results from this series are shown in Table 1. The packing densities were increased for each test to further maximize the potential for detonation. The reaction of the TATB in each case was extremely vigorous The threaded rods were broken during the first test and the end caps were destroyed. The rods did not break during the next two tests but were stretched considerably and the ignitor blocks were severely eroded by the high velocity, hot gas. However, it was clear that nothing approaching a detonation occurred. Strong combustion was the only result. The unreacted TATB was compressed into plugs by the pressure generated by the reaction. The HE in the plugs ceased to burn once the confinement was lost. The density of the plugs are also shown in Table 1. No signs of reaction were evident in the material inside of the plugs. However, the outside surface was blackened somewhat. Only ash and char remained from the final test. The original HE was nearly all consumed.

To put the previous results into perspective, three other explosives were also tested. Four tests were conducted using PBX 9501 molding powder (95% HMX, 2.5% Estane, 2.5% BDNPA-F), followed by one test each with flaked TNT and nitromethane (NM). These explosives were placed into the same confinement as used for shot B-9712. The two solid explosives were poured into the tubes in small increments and tamped lightly. All shots were fired at 30° C except for one that used PBX 9501 at 150° C. The three tests with PBX 9501 at 30° C all detonated with runup distances of approximately 200 mm. The last test at 150° C detonated with a runup distance of 140 mm. Neither the flaked TNT nor nitromethane detonated although they exhibited vigorous reactions similar to those of TATB. For these cases however, the explosive was entirely consumed.

Failure Thickness Of PBX 9502 As A Function Of Temperature

The wedges of PBX 9502 we used were similar to those described by Ramsay[2], and are shown in Fig. 1. The wedge angle was made as small as possible to avoid the effects of overdrive insofar as possible. The experimental configuration is shown in Fig. 2. The wedge and high temperature mating block were placed into an insulated box equipped with a resistance heater and fan. Once the desired temperature was reached, the lid of the box was removed and the wedge assembly was raised to meet the booster assembly. PBX 9501 was used as the booster. After the shot, the point at which the detonation failed was clearly indicated in the aluminum witness plate. The failure thickness was then calculated using this length and geometric relationships.

Fig. 3 shows the data from this study compared with that of Campbell[1] and Ramsay.[2] Campbell's data have been divided by two because he measured failure diameter, not failure thickness. Also shown is the line that he used to connect his data.

Fine wires that registered upon contact with the detonation front were placed across the top and bottom of the wedge. These provided indications of the transit time for various wedge thicknesses.

DISCUSSION

Deflagration To Detonation Transition In TATB

Rapid pressurization in the combustion zone must be present if DDT is to occur in a given explosive. This pressurization serves to drive the compaction waves that eventually form shocks subsequent to detonation. At ambient temperatures, the combustion velocity for TATB has been found to be at least an order of magnitude lower than that of HMX when tested at pressures from 2 to 15 kpsi, and it will not sustain self-deflagration at pressures less than 1500 psi.[10] It is apparent from the results of this study that the increase in temperature did not sufficiently accelerate the rate of combustion to create the rapid pressure rise required. This is the case even though TATB has a very high melting point, which has been found to correlate with early onset of unsteady burning and thus, DDT.[11] We have shown that even these conditions that are relatively conducive to convective combustion were not sufficient to overcome the very low combustion velocity and concomitant slow pressure rise. The low combustion velocity is undoubtedly a function of many effects, however, it is known that there are endothermic steps involved in the early decomposition of TATB which would serve to lower the velocity. Also, it has been postulated that ash formation on the particle surface could insulate the reactive material from the flame.

The reaction of TATB at 250° C did not consume all of the explosive, whereas both TNT and NM underwent complete combustion when tested at 30° C.

Failure Thickness Of PBX 9502 As A Function Of Temperature

Campbell and Engelke[3] showed that in heterogeneous explosives, two mechanisms are responsible for the energy release required to sustain detonation. The major components in these two mechanisms are hot spots and homogeneous burn. They found that at diameters near failure, only the hot spot mechanism sustains wave motion. This is used to explain the differences in the diameter effect curves between homogeneous and heterogeneous explosives. Campbell[1] found that for PBX 9502 at small diameters, the effect of temperature on detonation velocity is dominated by reaction rate whereas at large diameters, density effects predominate.

Our tests were conducted at low diameters (thicknesses) and thus we expect that hot spots are responsible for the energy release, and that the reaction rate predominates over the density effect. The failure width appears to approach a constant value of approximately 2 mm at high temperatures. Thus, as the temperature increases, the reaction rate also increases to a point at which no higher rate is possible.

These data compare favorably with those of Belyaev and Kurbangalina[12] where they measured the temperature effect on failure diameters of nitroglycerin (NG) and liquid TNT. They reported a reduction in the failure diameter of TNT from ~60 mm to ~8 mm as the temperature increased from 80° C to 260° C, with asymptotic behavior similar to that found in this study occurring at high temperature.

If simple Arrenhius kinetics are assumed, then the behavior we have noted in PBX 9501 is readily explained. The high temperature limit of the failure diameter of this material, and by extension, the reaction zone thickness, is reached in the vicinity of 250° C.

CONCLUSIONS

We have shown that even under severe confinement and at the maximum possible temperature, TATB will not transit from a deflagration to a detonation in 305 mm when ignited by a flame. These results conclusively demonstrate the large increase in the margin of safety that is accomplished when TATB is used in place of HMX.

It has also been shown that the failure thickness of PBX 9502 approaches a value of ~ 2 mm (or a failure diameter of 4 mm) at 250° C. This value appears to be the lower limit.

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Table 1

Shot No.	TATB Bulk Density (g/cm3	Temperature (°C)	TATB Consumed /Original (g)	Plug Density (g/cm3)
	1.18			
B-9686	1.23	200	5/184	1.8
B-9688	1.30	200	84/190	1.6
B-9712		250	198/200	NA

FIGURE CAPTIONS

1. Schematic of PBX 9502 wedge. Drawing is not to scale. Units are in mm.

2. Schematic of heated wedge experimental configuration.

3. Comparison of data from this study with those of Ramsay[2] and Campbell.[1]

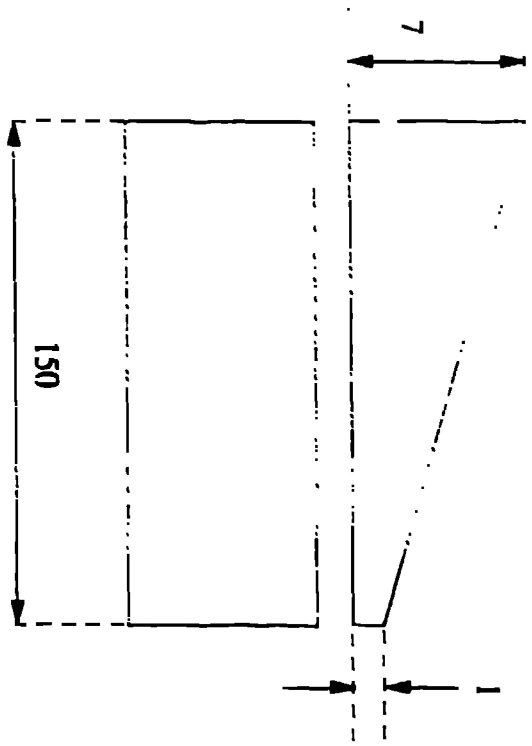
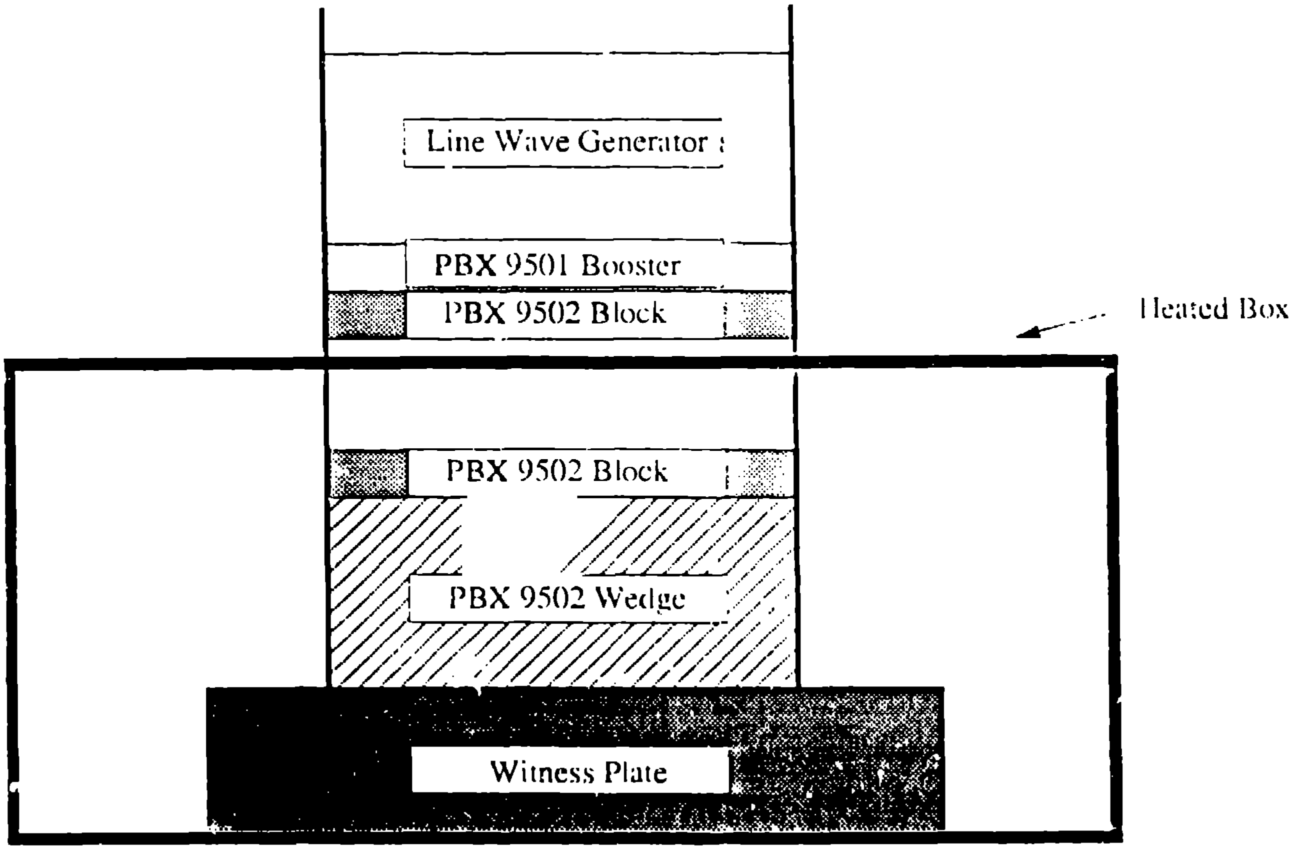


Fig. 1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PBX 9501 Booster
PBX 9502 Block
Heated Box
PBX 9502 Block
PBX 9502 Wedge
Witness Plate

[illegible]

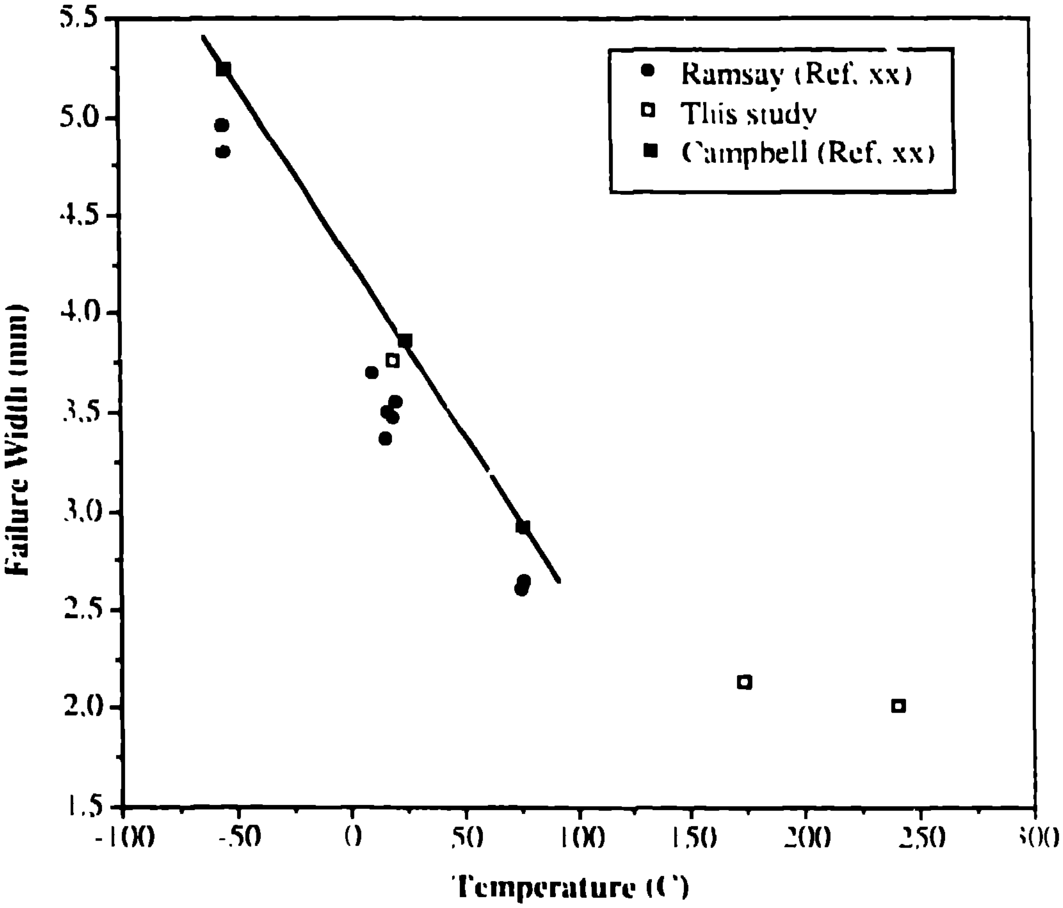
● Ramsay (Ref. xx)
☐ This study
■ Campbell (Ref. xx)
Failure Width (mm)
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
-100
-50
0
50
100
150
200
250
300
Temperature (C)

Fig 3