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# Run distance to detonation in a TATB/HMX-based explosive

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**Abstract**: By means of optical fibre probe, optical-electrical converter, and oscillograph diagnostic technique, the run distance to detonation was measured as a function of initial shock pressure in a TATB/HMX-based explosive. High amplitude and short duration shock stimuli generated by an electric gun were used to initiate the cylindrical wedges of explosive material. The experimental technique was described, and the results in the form of POP plots for the TATB/HMX-based formulation were presented. These experimental data may give some insight into the effect of pulse duration on the initiation and growth to detonation characteristics in insensitive high explosives. For the short-duration shock loading, the effect of the pulse duration on the run distance to detonation of explosive is obvious. Under the same experimental conditions, the longer the pulse duration , the shorter the run distance to detonation. And for the same pulse duration, the higher the loading pressure, the shorter the run distance to detonation.

**Key words**: mechanics of explosion; run distance to detonation; short-duration shock initiation; TATB/HMX-based explosive; electric gun

## 1 Introduction

Insensitive high explosives (IHEs) such as TATB provide significant improvements in safety for the HE formulator when compared with HMX and RDX[1]. In order to exploit the increased safety, it is necessary to characterize the response of IHEs to a variety of stimuli. In this paper, the run distance to detonation as a function of shock pressure has been measured directly in a TATB/HMX-based explosive. The effect of pulse duration on the initiation and growth to detonation characteristics in this high explosive has also been studied. Two well-known techniques have been combined: the electric gun, which provides a high pressure, short shock pulse of known amplitude and duration, and the explosive wedge method, where the progress of a propagating reaction front can be followed as a function of distance through the explosive. The measuring method of run distance to detonation in explosive is described here.

## 2 Experimental set-up and method

Electric gun has proven to be a good tool ideally suited to short-duration shock initiation studies of explosives[2]. It can produce a well-characterized, planar and reproducible shock stimulus that can

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be equaled in precision only by the much more costly and complicated explosive lens technique.

The principle of the electric gun is that a thin polyester flyer disc along a short barrel of PMMA is accelerated to a high velocity to impact an explosive sample[2~3]. The drive for the flyer is provided by the expanding plasma of an electrically-exploded metallic foil confined behind the flyer. The flyer velocity is controlled by changing the charging voltage of the capacitor, i. e. the energy discharged through the foil. According to the flyer velocity and the Hugoniot data of the flyer and explosive, the input shock pressure in the target can be calculated. In addition, a knowledge of the flyer density and thickness allows the pulse duration of shock pressure to be calculated. Table 1 gives details of the electric gun used in the present study.

**Table 1 The parameters of the electric gun**

| Parameters | Values |
|---|---|
| Storage capacitance | 31. 8 μF |
| Circuit resistance | 11 mΩ |
| Inductance | 49 nH |
| Charging voltage | ～30 kV |
| Discharging period of short circuit | 7. 9 μs |
| Stored energy | 14. 4 kJ |
| Mylar flyer | ∅19 mm×(0. 07, 0. 15 and 0. 20 mm) |
| Aluminum foil | 20 mm×20 mm×0. 028 mm |
| PMMA barrel | ∅19 mm×(6 and 8 mm) |
| Flyer simultaneity at impact | ⩽25 ns |

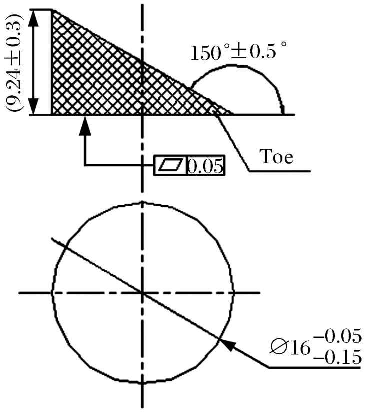


Fig. 1 The explosive wedge

The explosive samples are in the form of cylindrical wedges with the diameter of 16 mm, the toe thickness of less than 0. 5 mm and the toe angle is 30°. Because of the difficulty of machining, the toe thickness was not uniform and should be measured with tool microscope before assembly. Explosive composition TATB/HMX/others is 80/15/5, and its density is (1. 84±0. 01) $g/cm^3$. Figure 1 shows the full details of the explosive samples.

The run distance to detonation is measured by using optical fibre detectors and an oscillograph to record the impact signals when the shock wave, sub-detonation and detonation wave impact the optical fibres, and the produced optical signals are converted to the electrical signals by the optical-electrical converter. The time of impact follows the progress of the reaction wave from sub-detonation input shock to stable detonation. The end face of the optical fibre is coated by a thin layer of aluminum film to cover the light of detonation products and to gain neat signals. The optical fibre probes, 0. 05 mm diameter, are aligned to be placed across the angled face of the explosive wedge with the help of a blacked PMMA holder. The precise space between two optical fibres are measured with the tool microscope. For every experiment, 16 optical fibres are used and arrayed as in Figure 2. Figure 3 is the photo of the experimental explosive wedge and optical fibre array.

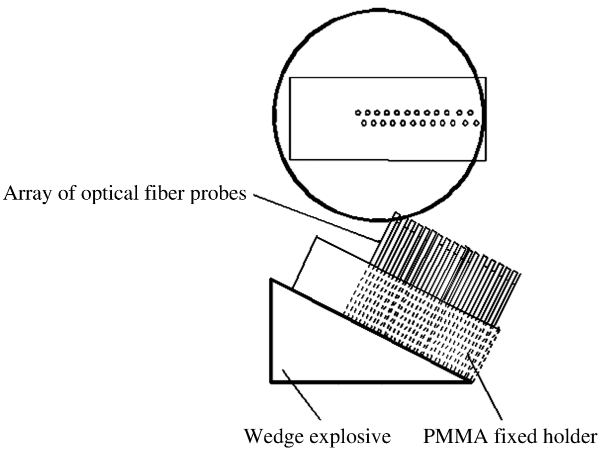


Fig. 2 Sketch of the holder/optical fibre array/ HE wedge in the experimental configuration

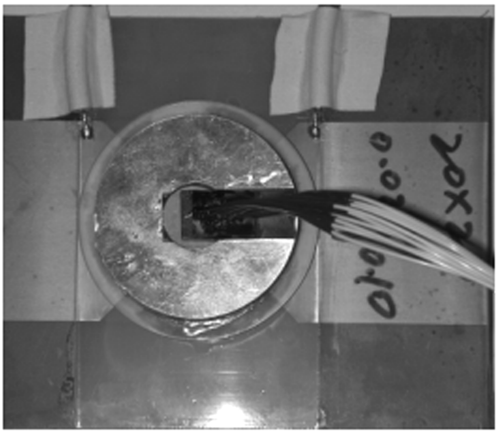


Fig. 3 The photo of the experimental target and optical fibre array

## 3 Results

As can be seen in Table 1, the diameter of the flyer is larger than that of the target in order to produce one-dimensional planar shock wave in the explosive wedge. According to the Hugoniot data of the materials and the velocity of the flyer, the input shock pressure is calculated. The velocity of the flyer is measured by VISAR(velocity interferometer system for any reflector). Based on the measured velocities of the flyer, the coefficients of the electrical Gurney formula are determined, which describes the relationship between the velocity and the burst current density of the foil. Since no Hugoniot is found for our research explosive, that of another explosive, TATB/bond(95/5) is used. Because our research explosive contains only 15% HMX, and the Hugoniots of HMX and TATB are similar over the limited pressure range studied[2], the error is very little. Table 2 shows the Hugoniot data of the materials used, where $\rho$ refers to density. Table 3 shows the experimental conditions, where $l$ ,$b$, $\delta_b$ refer to the length, width and thickness of bridge foil respectively;$d$, $\delta_f$ refer to the diameter and thickness of flyer respectively; $J$ refers to current density of foil explosion, $v$ to velocity of flyer, $p_H$ to shock pressure, $\tau$ to duration of pressure.

**Table 2 Shock Hugoniot data of the used materials**

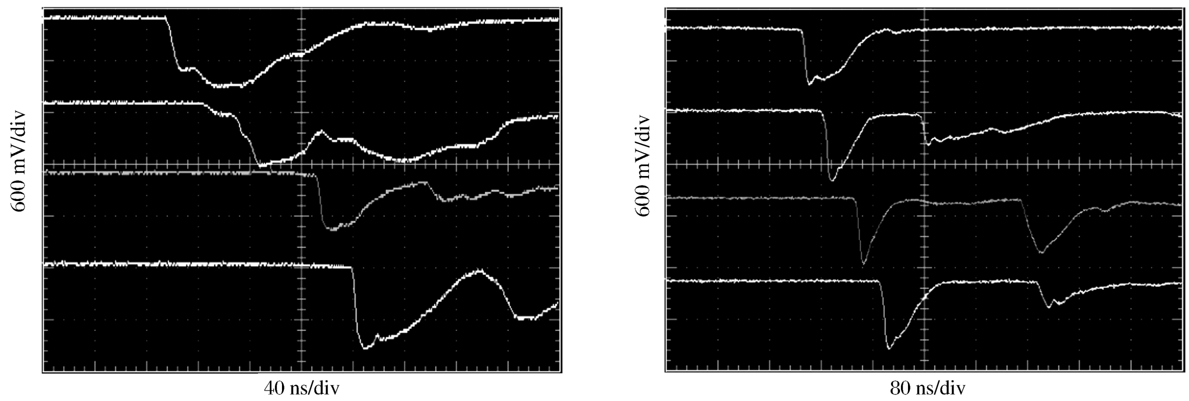
| Materials | $\rho$ /(g/cm$^3$) | Shock Hugoniot expression |
|---|---|---|
| Mylar | 1.40 | $D = 2.54 + 1.49u$ [4] |
| TATB/Bond(95/5) | 1.89 | $D = 2.559 + 1.441u$ [5] |

**Table 3 Experimental conditions**

| $l$/mm | $b$/mm | $\delta_b$/mm | $d$/mm | $\delta_f$/mm | $J$/(GA/m$^2$) | $v_f$/(km/s) | $p_H$/GPa | $\tau$/$\mu$s |
|---|---|---|---|---|---|---|---|---|
| 20 | 20 | 0.028 | 19 | 0.20 | 357.86 | 2.870 | 10.71 | 0.089 |
| | | | | | 373.83 | 3.071 | 11.83 | 0.087 |
| | | | | | 393.53 | 3.326 | 13.28 | 0.084 |
| | | | | | 414.75 | 3.609 | 15.04 | 0.080 |
| | | | | | 430.76 | 3.828 | 16.45 | 0.079 |
| | | | | 0.15 | 373.83 | 3.483 | 14.25 | 0.061 |
| | | | | | 386.50 | 3.668 | 15.46 | 0.060 |
| | | | | | 412.39 | 4.056 | 17.96 | 0.057 |
| | | | | | 413.30 | 4.070 | 18.05 | 0.057 |

Figure 4 shows the typical record of the oscillograph, the time of impact is determined by the onset of the zooming signal. And Figure 5 shows the processed result. In Figure 5 $x$ refers to the distance of each optical fibre probe to the end face of PMMA fixed holder, $t$ to the time of shock wave reaching each optical fibre probe.

As can be seen in Figure 5, the reaction wave shows an initial acceleration up to the T point where the maximum velocity is reached and the velocity remains constant. Compared with the velocity of stable detonation measured, it is determined that the T point corresponds to the onset of stable detonation.


(a) No. 1~4 optical fibre probes　　(b) No. 5~8 optical fibre probes

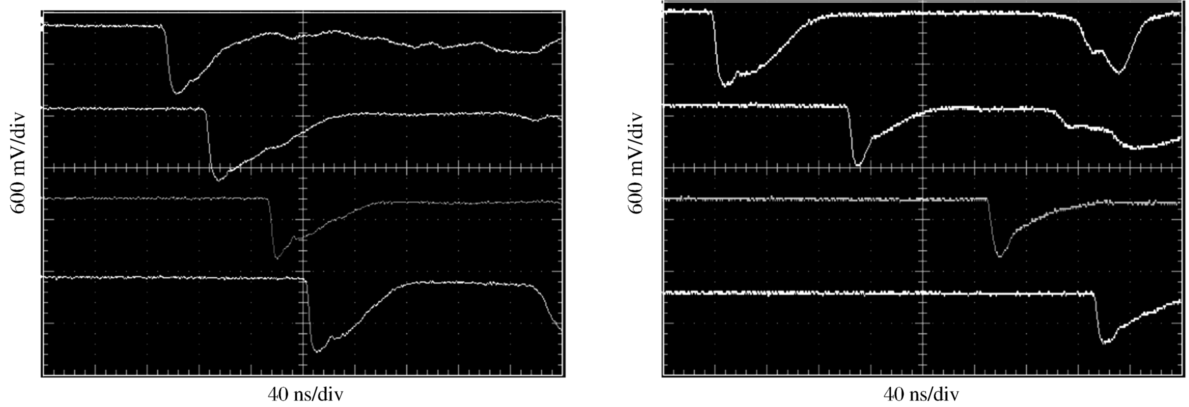

(c) No. 9~12 optical fibre probes　　(d) No. 13~16 optical fibre probes

Fig. 4 Typical impact signals of optical fibre probes

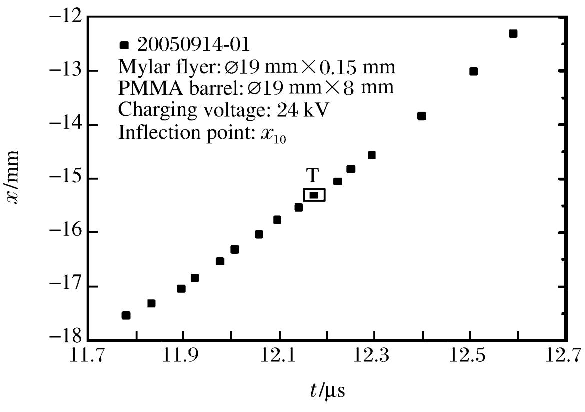


Fig. 5 The processed result of some experimental conditions

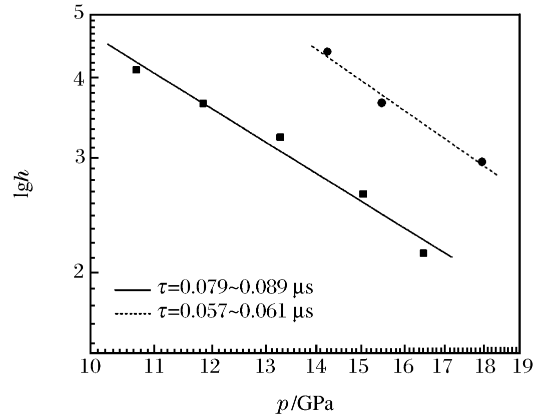


Fig. 6 POP plots for the studied explosive at different pulse durations of loading pressure

POP plots are delineated in Figure 6 for each pulse duration, except the pulse duration of 0.021 ~0.024 μs which fails to detonate the explosive at our experimental pressures. In Figure 6 $h$ and $p$ denote run distance to detonation and shock pressure respectively.

The corresponding POP relationship expressions are gained by linear fitting given in Formulas (1) to (2)

$$\lg h = 2.141 - 1.471 \lg p \qquad \tau = 0.079 \sim 0.089\ \mu\mathrm{s} \tag{1}$$

$$\lg h = 2.545 - 1.657 \lg p \qquad \tau = 0.057 \sim 0.061\ \mu\mathrm{s} \tag{2}$$

## 4 Discussions

Here the pulse duration is less than 0.1 μs, which is assumed to be a short pulse. For the short-duration shock loading, the effect of the pulse duration on the run distance to detonation of explosive is obvious. Under the same experimental conditions, the longer the pulse duration, the shorter the run distance to detonation (seen in Figure 6). And for the same pulse duration, the higher the loading pressure, the shorter the run distance to detonation.

The influencing factors on experimental measurement should be paid attention to. The gap between the explosive wedge and the steel barrel at the toe causes the lateral rarefaction wave to weaken the strength of the input shock pressure. So the run distance to detonation will become longer, or it needs higher input shock pressure to detonate the explosive in the short distance. For thinner flyer, i. e. the shorter pulse, the back rarefaction comes earlier, so it needs higher input pressure or longer distance to detonation. Here the explosive isn't initiated to detonation by the pulse with duration of 0.021 ~0.024 μs at our experimental pressures, the possible reasons are that the state of the flyer is bad, perhapse it is destroyed and the velocity becomes low, besides the strong influence of the lateral and back rarefaction waves at the same time. Therefore it needs more energy to compensate for the loss caused by rarefaction waves. Considering these two rarefaction waves, it can be understood that the run distance to detonation is a little longer.

Let's look at the data of PBX9503 provided in the reference [4]. The main compositions of these two explosives are the same except the type of bond, and the pulse duration of loading pressure is 0.8 ~0.11 μs which is wider than our pulse duration of loading pressure. The amplitude of the loading pressure in reference [4] is 15 ~26 GPa. For our experiments, the amplitude of the loading pressure with pulse duration of 0.079 ~0.089 μs is not more than 18 GPa, and it is 14 ~19 GPa for the pulse duration of 0.057 ~0.061 μs. Compared the conditions of the reference [4] with ours, it can be concluded that our measured results are reasonable.

## 5 Conclusions

By combining the electric gun and explosive wedge techniques, the run distance to detonation has been measured directly in a TATB/HMX-based explosive with the optical fiber probe and optical-electrical converter. POP plots and expressions have been constructed by measuring the run distance as a function of input shock pressure for different pulse duration of loading pressure. The experimental results show that the pulse duration has effect on the run distance to detonation. For the short-duration shock loading, under the same experimental conditions, the longer the pulse duration, the shorter the run distance to detonation. And for the same pulse duration, the higher the loading pressure, the shorter the run distance to detonation.

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# 一种以 TATB/HMX 为基炸药的到爆轰距离*

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**摘要：**利用光纤探针/光电转换器/示波器技术和楔形炸药块方法，采取电炮驱动薄飞片冲击加载产生高压短脉冲激励的装置，测量了一种以 TATB/HMX 为基炸药的到爆轰距离，研究了到爆轰距离与初始冲击波压力幅值和脉宽的关系，给出了该炸药的 POP 曲线和表达式。实验结果有助于了解压力脉宽对钝感炸药的冲击起爆和爆轰成长的影响。对于短脉冲冲击加载，入射压力脉宽对炸药的到爆轰距离影响明显，相同实验条件下，压力脉宽越长，炸药的到爆轰距离越短；相同压力脉宽下，加载压力越高，炸药的到爆轰距离越短。

**关键词：**爆炸力学；到爆轰距离；短脉冲冲击起爆；以 TATB/HMX 为基炸药；电炮

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