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A B S T R A C T

Results of shock initiation experiments on tetryl and A-5 are presented. A gun system was used to produce both sustained and short-duration pressure pulses from which the critical energy for initiation for these explosives was calculated. For tetryl, the value was $420 \pm 24 \text{ kJ/m}^2$. For A-5 the value was $528 \pm 26 \text{ kJ/m}^2$.

INTRODUCTION

Excess transit time is a useful measure of the rapidity of buildup to steady-state detonation in a high explosive subjected to a shock wave and is defined as the difference between the observed shock (and detonation) transit time through an explosive sample and the calculated transit time for a steady-state detonation through the same sample. The relative ease of measuring excess transit time makes it an important tool for making engineering estimates of the relative shock sensitivities of various explosives to shock waves of different amplitudes. Ramsay and Popolato¹ have shown that for a given explosive, a very nearly linear relationship exists between the logarithm of the measured excess transit time and the logarithm of the entering pressure. Thus, only a few experiments are required to characterize in a reasonable fashion the excess transit time-initiating pressure relationships for a particular explosive where the time duration of the initiating shock at least approximates the time required to achieve detonation. However,

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for a given amplitude shock wave, as the duration of the initiating shock becomes shorter, the excess transit time becomes longer.^{2,3} This lengthening of the excess transit time as the energy transferred to the explosive is lessened may be used to calculate another facet of explosive shock sensitivity, the critical initiation energy.⁴ Walker and Wasley³ have shown that the minimum energy to initiate a heterogeneous explosive (the "critical energy") is approximately a constant over a wide range of initiating pressures. Thus, measuring the minimum initiation energy at one pressure gives a good approximation of the minimum initiation energy required at any other. One advantage of the present series of experiments over a go/no go approach is that it gives values for critical energy that are virtually independent of sample size or geometry while a go/no go approach would not. The question of whether or not there is a "critical pressure" below which shock initiation is not possible will not be dealt with here. However, there is some evidence that such a situation exists for PBX-9404 at pressures an order of magnitude less than those being presently considered for tetryl and A-5. Another question not being dealt with experimentally at this time is the effect of failure diameter on the critical energy. It seems most probable that as the failure diameter of an explosive is approached, the explosive must achieve detonation after a shorter and shorter run distance if it is to detonate at all. This would result in an increase in the energy per unit area required to achieve detonation, particularly at lower initiating pressures. Under these circumstances, the apparant "critical energy" would be dependent on the entering pressure and would have a higher value at the lower pressures.

Tetryl and its replacement, A-5, are normally used at about 95% of theoretical density. This means that samples are normally pressed to shape

either at some constant volume to control density or at some relatively low constant pressure. One result of these procedures is that density variations within a piece can be rather large. In the present experiments, it is thought that density variations played an important role in causing spread in the data. This effect is particularly magnified by experiments close to the critical energy, where randomness in the formation of reacting initiation sites might also contribute to data scatter.

EXPERIMENTAL

A schematic drawing of a tetryl flyer-plate/gun experiment is given in Fig. 1. The A-5 experiments use a single thickness for accurate timing plus a glued-on wafer to determine that detonation had been achieved. Piezo-electric pins are used to determine flyer plate velocity, time of arrival and tilt at the HE front surface, and shock arrival times at the various back surfaces of the HE. The planarity of the flyer-plate is maintained by a carbon foam disk between the front of the projectile and the flyer-plate, a method reported by Wasley, et al.⁵ The air gun used to propel the flyer-plate assembly has a 100 mm-diameter, 18 m long, smooth-bore barrel, and it has a velocity capability of about 1.7 km/sec with an 0.80 kg projectile. A reduced pressure of 10 Pa or less is maintained over the test sample prior to impact of the flyer-plate.

The tetryl and A-5 samples that were obtained from Mason and Hanger-Silas Mason Co., Inc., Burlington, Iowa, had been pressed to shape from powders with the respective designations of Mil T-00339-A and Mil E-14970-A. The densities of the tetryl pieces were determined by a water-immersion method, which was satisfactory if the weighings were done rapidly. The average value was 1.655 Mg/m^3 with a range of $\pm 0.004 \text{ Mg/m}^3$. A-5 was much

more difficult to work with. The fragile pieces absorbed water too rapidly to permit density determination by immersion methods, so densities were calculated from the dimensions of the pieces, and the weights in air. The average value was 1.710 Mg/m^3 with a range of $\pm 0.017 \text{ Mg/m}^3$.

CALCULATIONS

It has been shown in other work⁴ that the initiation data taken on an explosive at near the critical energy can be represented by the equation,

$$(X-1)(Y-E_c) = C, \quad (1)$$

where X is the reduced excess transit time, Y is the flyer-plate kinetic energy, E_c is the critical energy, and C is a constant. Reduced excess transit time is a measure of the lengthening of the excess transit time as the pulse length (and energy) is decreased. It is the ratio of the observed excess transit time from a thin foil initiation experiment to that from a thick foil initiation experiment at the same foil velocity. The constant C was found to be 3.22^4 for PBX-9404. Because there is not enough data to accurately determine C in the present experiments, the previously determined value will be used in the calculation of critical energy for tetryl and A-5. The uncertainty in the value of C causes some uncertainty in the value of the critical energy, particularly at the higher flyer-plate kinetic energies. For this reason, only the lowest energy thin foil initiation experiments will be used to calculate critical energy.

The Hugoniot of tetryl used to calculate the entering shock pressures in the tetryl experiments was given by Lindstrom.⁶ The Hugoniot used to calculate the A-5 pressures was an average of the Hugoniot given by Lindstrom⁷ for PBX-9407 at 90% theoretical density and the Hugoniot given by Ilyukin⁸ for pure RDX at 99% theoretical density. This gave the equation:

$$U_s = 2.10 + 1.80 U_p,$$

where U_s is the shock velocity and U_p the particle velocity in the explosive in km/s. The pressures calculated from this Hugoniot for A-5 are good to approximately 5% at the pressures of interest.

RESULTS

Table 1 is a summary of the sustained-pulse initiation data on tetryl and A-5. Excess transit time was determined for the tetryl using a detonation velocity calculated from the density.⁶ Detonation velocity for A-5 was estimated using the method of Urizar.⁹ Fig. 2 is a display of the log of the excess transit time vs. the log of the initiating pressure for both tetryl and A-5. The least-square fit to the data is also shown. Over the pressure range tested at the densities used, A-5 is slower to build to detonation than tetryl.

Table 2 is a summary of thin-pulse initiation data on tetryl and A-5. The average value for the critical energy of tetryl is $420 \pm 24 \text{ kJ/m}^2$. The average value for the critical energy of A-5 is $528 \pm 26 \text{ kJ/m}^2$. In each case the highest value measured was not included in the average for reasons stated in the calculations section.

One aspect of booster explosive sensitivity that was not investigated was the effect of density on critical energy. It is known that lower density favors more rapid build-up to detonation. It is not clear that critical energy would necessarily follow this trend, since the definition of critical energy does not include run distance or rapidity of detonation build-up. One of the goals of future experiments is to determine critical energy as a function of density for representative explosives.

Table 1. Sustained-pulse initiation data for Tetryl and A-5.

Explosive	Flyer-Plate Thickness (mm)	Flyer-Plate Velocity (km/s)	Flyer-Plate Density (Mg/m ³)	Entering Pressure in HE (G Pa)	Observed Excess Transit Time (μ s)	Excess Transit Time from Data Fit (μ s)
Tetryl	9.53	0.652	8.546	3.04	0.521	0.525
		0.769	8.546	3.73	0.329	0.327
		0.779	8.546	3.79	0.325	0.315
		0.826	8.546	4.05	0.263	0.270
A-5	9.53	0.625	8.546	2.83	0.750	0.864
		0.731	8.546	3.44	0.667	0.564
		0.845	8.450	4.17	0.360	0.370

Table 2. Tetryl and A-5 thin-pulse initiation data. Brass flyer plates 0.273 mm thick with a density of 8.517 Mg/m³ were used.

Explosive	Flyer-plate velocity (km/s)	Flyer-plate kinetic energy (kJ/m ²)	Entering pressure in HE (G Pa)	Observed excess transit time (μs)	Calculated excess transit time (μs)	Reduced excess transit time	Calculated critical initiation energy (kJ/m ²)
Tetryl	0.626	10.90	2.89	3.454	0.591	5.84	429
	0.671	12.52	2.94	1.151	0.568	2.03	393
	0.706	13.86	3.35	0.817	0.420	1.95	437
	0.831	19.20	4.10	0.450	0.263	1.71	614
A-5	0.539	8.08	2.35	No detonation			> 338
	0.719	14.38	3.39	2.093	0.582	3.60	550
	0.722	14.50	3.41	1.659	0.575	2.89	535
	0.725	14.62	3.44	1.233	0.564	2.19	498
	0.811	18.29	4.01	0.837	0.403	2.08	640

Fig. 1. Schematic representation of flyer plate/gun experiment showing pin placement.

Fig. 2. Excess transit time vs. initiating pressure for tetryl and A-5.

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