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SHOCK SENSITIVITY OF THE EXPLOSIVE 2-(5-CYANOTETRAZOLATO) PENTAAMINE COBALT(III) PERCHLORATE (CP)

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ABSTRACT

The inorganic explosive, 2-(5-Cyanotetrazolato) Pentaamine Cobalt(III) Perchlorate, more commonly designated CP, is used in a number of hot-wire initiated deflagration-to-detonation detonators. Analyses of the safety aspects of these detonators are dependent upon utilizing shock initiation sensitivity data on this explosive where sensitivity is defined as the amplitude (P) and duration (τ) of the shock stimulus which produces a 50 percent probability of initiation. In this work the shock senstivity of CP powder pressed to 1.50 Mg/m^3 bulk density was determined using flyer plate impact techniques which provided pulse durations of 0.17μs and 0.23μs and pulse amplitudes of 0.8 to 2.3 GPa. Impact tests were conducted in air and vacuum, and with flyers of different area.

It was necessary to develop a new test technique to generate flyer velocities to bracket the threshold of initiation for this study. This was done by electrically exploding a metal foil against a lucite shock-moderator from which a plastic flyer lifted off at a controlled velocity. The energy source was a large capacitor bank and provided flyer velocities repeatable within 7 percent and with a planarity of 30 ns or less.

The pressure thresholds for detonation of CP were found to be 1.75 GPa and 1.40 GPa, for pulse durations of 0.17μs and 0.23μs respectively. There was no discernible difference in response between samples tested in air or vacuum, or with flyers of different area, within experimental error.

DISCLAIMER

INTRODUCTION

An inorganic explosive, 2-(5-Cyanotetrazolato) Pentaamine Cobalt(III) Perchlorate (CP), is presently being developed for use in detonators by Sandia National Laboratories/Albuquerque (SNLA)(Ref. 1). The Air Force is also interested in this material because of its possible use in Air Force weapon systems. Data on shock initiation sensitivity are required for material evaluation. CP shock sensitivity testing was performed by SNLA using an exploding foil driven flyer plate technique (Ref. 2); however, velocities below 1.2 mm/μs could not be achieved and most of the samples detonated at this impact condition. The test technique developed for the current test program had to include impact velocities below 1.2 mm/μs to insure that CP threshold conditions were bracketed. Therefore, flyer velocity requirements set for the test were 0.5 to 1.5 mm/μs.

Task requirements included providing shock inputs to the CP explosive at pulse widths between 0.01 and 0.20μs. An impactor with a mechanical shock impedance less than that of CP was required in order to provide a well defined pulse width. A flyer impacting a higher impedance target results in essentially a step input and release with the pulse width approximately the time required for the shock wave to transit the flyer thickness twice. The impact velocity was used to calculate impact stress amplitude based on Hugoniot data for the flyer material and CP explosive. Flyer impact had to be planar to produce definable shock loading conditions. The test fixture had to be capable of operating in either air or vacuum in order to test the effect on flyer velocity required for detonation with and without an air cushion between the flyer and explosive sample. A positive means of determining whether or not the sample detonated during the impact test was required.

A test technique was developed to accelerate a Mylar* flyer off a shock moderator using an exploding foil to generate a shock in a moderator plate. Flyer thickness was varied to control shock pulse width and flyer velocity was varied to generate different shock amplitudes.

*DuPont registered trademark for polyester film.

EXPERIMENTAL TECHNIQUE

A test fixture was designed to provide the required impact conditions. The fixture was capable of being used with air or vacuum between the flyer and explosive and provided posttest recovery of the sample. The CP test samples, provided by SNLA, had a density of 1.50 Mg/m^3, and were pressed into a steel ring, 2.54-mm thick, 6.35-mm OD by 4.72-mm ID.

A steel target plate was designed with a recess to position the explosive sample. A dent in the recess at posttest examination meant detonation had occurred. Any reaction less than detonation would not dent the steel. A 1.52-mm thick standoff ring was used between the moderator and target. An O-ring was used outside the standoff to provide a seal if the test was conducted in vacuum. Figure 1 shows the complete test assembly.

The flyer size used throughout the developmental portion of this task was 25.4 x 25.4-mm square. The CP explosive sample was 4.72-mm in diameter so the flyer would impact the steel ring as well as the explosive, and possibly produce a shock wave focusing effect in the CP. Shock wave focusing would cause an apparent lowering of impact velocity required for detonation (Ref. 5). It was decided to conduct shock sensitivity tests with two flyer sizes (25.4 x 25.4-mm square, and 3.96-mm diameter) to determine what effect hitting the steel ring had on the impact condition required for detonation.

Flyer velocity data were required to compute the shock input into the CP sample. Measuring flyer velocity was desired for each shot but the closed explosion chamber precluded streaking camera optical access. Therefore, a number of shots were performed to generate flyer velocity vs bank charge voltage calibration curve. All subsequent velocity determinations were then taken from the calibration curve.

CP SHOCK SENSITIVITY TESTS

A. Flyer Velocity Calibration

Seventeen shots were performed to provide flyer plate velocity

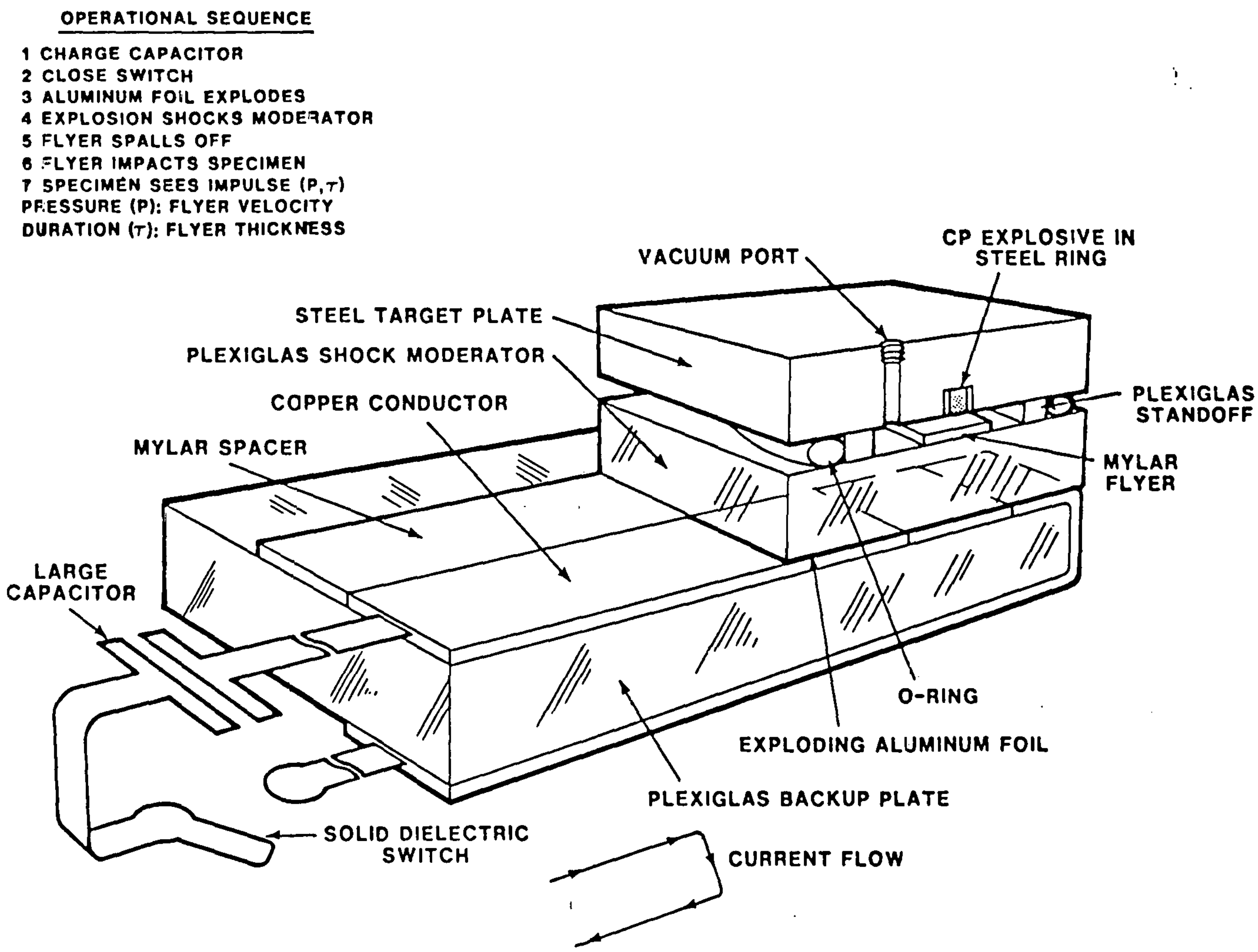

Figure 1. Sectional view of exploding foil test fixture.

calibration data for use with the explosive tests. Three of the tests were conducted with the flyer in vacuum and then three in air with no target. The shots were conducted to determine if vacuum conditions made any significant difference in flyer velocity at a given capacitor bank charge. The flyer velocity calibration and test shots were performed in a vacuum of 13.3 Pa or less. The maximum flyer velocity variation from air to vacuum was less than 7 percent, within the repeatability of the test setup, so the remaining calibration tests were conducted in air.

Eleven tests were run with the 0.25-mm thick flyer. Three shots with the 0.33-mm thick flyer showed no significant (less than 5 percent) velocity change from the 0.25-mm thick flyer. The analytical fit to the data points is within +4.9 to -7.9 percent and is described by the equation:

$$V_f = 0.4692 + 0.0075\ kV + 0.004\ kV^2$$

where

V_f = flyer velocity (mm/μs)

kV = bank charge voltage (kV)

The equation was used to compute flyer velocity for the explosive tests with the 96.8μF capacitor bank charge voltage ranging from 15 to 35 kV.

B. Test Results

Thirty-nine experiments were performed on the CP specimens. Nineteen of the tests were conducted using the small 3.96-mm flyer in a vacuum. The two flyer thicknesses used were 0.25 and 0.33-mm. Six tests (3.96-mm diameter x 0.33 thick flyers) were conducted in air to evaluate the effect on shock sensitivity of having an air cushion between the flyer and explosive. Ten tests were conducted with the large 25.4-mm square flyers to determine if hitting the steel ring produced an apparent change in CP shock sensitivity. The slight detonation threshold differences of air vs vacuum and large vs small flyer were less than the probable error in the flyer velocity calibration curve.

Calculations made to determine flyer velocity were based on the velocity calibration/bank voltage equation. Stress calculations were based on the following Hugoniot relationships:

Mylar:

$$\sigma = 2.506u_p + 4.86u_p^2 - 1.93u_p^3 \quad \text{(Ref. 3)}$$

CP:

$$\sigma = 0.704u_p + 3.503u_p^2 \quad \text{(Ref. 4)}$$

where

σ = stress (GPa)

u_p = particle velocity (mm/μs)

Pulse width calculations were based on:

$$\tau = \frac{2t}{U_s}$$

$$U_s = \frac{\sigma}{u_p \rho}$$

where

τ = pulse width (μs)

t = flyer thickness (mm)

U_s = shock velocity (mm/μs)

σ = stress (GPa)

u_p = particle velcity (mm/μs)

ρ = density (gm/cm^3)

The shock initiation sensitivity under the various impact conditions is given in Figure 2. The dashed lines denote the lowest stress at which detonation occurred. Detonation threshold data are presented in Table 1 for each test condition.

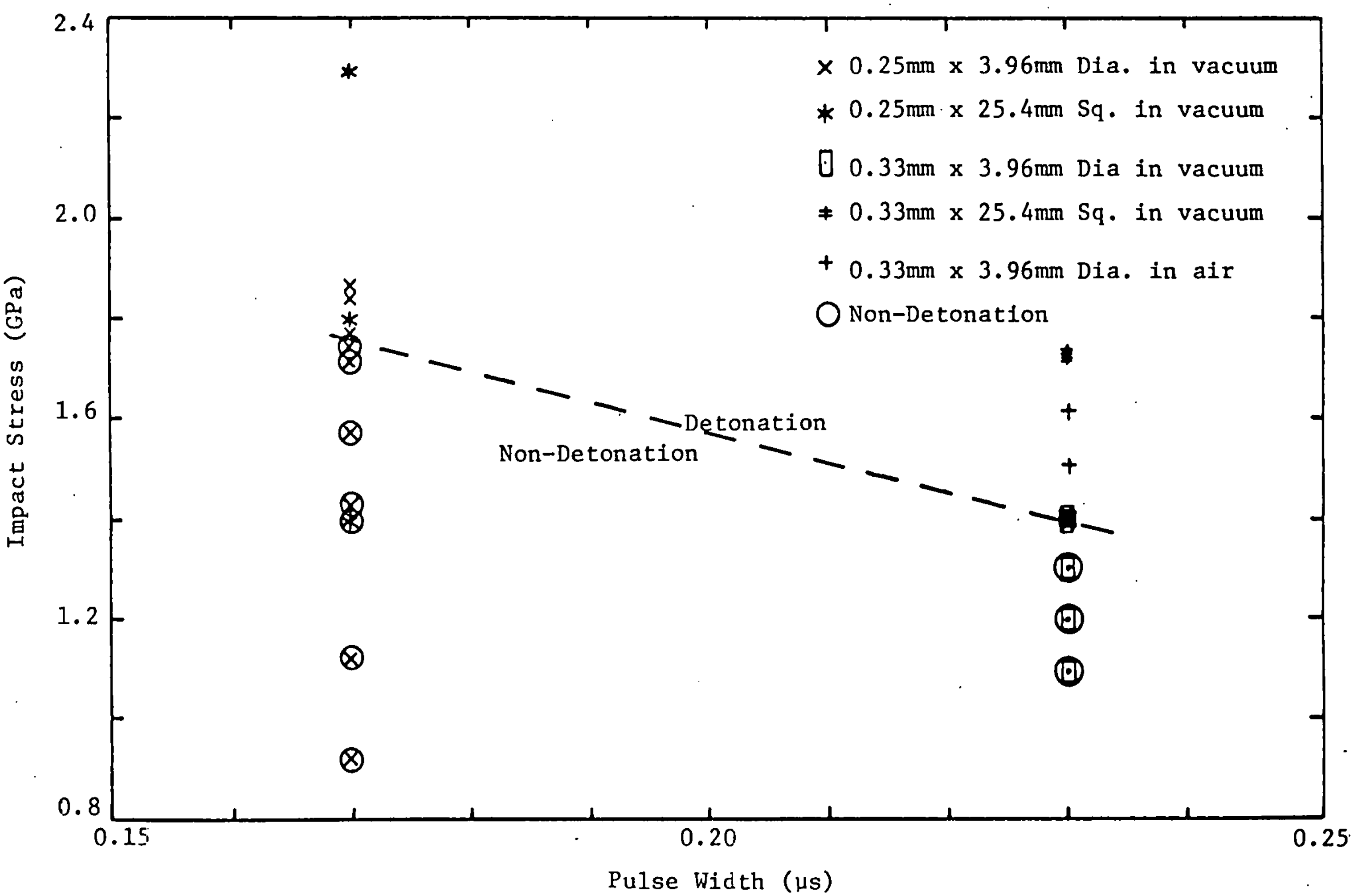

Figure 2. Shock initiation sensitivity of CP

TABLE 2. SUMMARY OF CP DETONATION THRESHOLD RESULTS

	Test Condition (Flyer Size/Environment)				
	0.25-mm Thick x 3.96-mm Dia. Vacuum	0.33-mm Thick x 3.96-mm Dia. Vacuum	0.25-mm Thick x 25.4-mm Square Vacuum	0.33-mm Thick x 25.4-mm Square Vacuum	0.33-mm Thick x 3.96-mm Dia. Air
Lowest V_f Required for Detonation (mm/μs)	1.03	0.90	1.00	0.90	0.91
Stress (GPa)	1.75	1.43	1.67	1.42	1.44
Nominal Pulse Width (μs)	0.17	0.23	0.17	0.23	0.23

C. Discussion of Results

There was no discernible difference in response between samples tested in air and vacuum, within experimental error. The different flyer sizes (area) also produced no discernible difference in initiation sensitivity even though there was a difference of about 40 percent in contact area between the two flyer sizes. Evidently the smaller flyer (3.96-mm) was so much larger than the failure diameter of the CP, that a still larger flyer produced no difference in results.

The CP shock sensitivity tests defined the threshold of detonation at two pulse widths. A stress input of 1.75 GPa was required for detonation at a pulse width of 0.17μs, and 1.40 GPa required at 0.23μs. The threshold points were calculated from the velocity calibration curve which has an accuracy of +4.9 to -7.4 percent. The shock sensitivity tests provided part of the data required to characterize the shock sensitivity of CP explosive. More useful characterization would include data points at pulse widths from 0.01 to 0.15μs. These pulse widths could not be achieved with this exploding foil driven flyer test technique because simultaneity of impact with thin flyers could not be demonstrated.

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