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CHARACTERIZATION OF DETONATION IN CONFINED CHARGES OF AMMONIUM PERCHLORATE SENSITIZED WITH SMALL AMOUNTS OF NITROGUANIDINE

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ABSTRACT

In previous work sympathetic detonation was achieved in ammonium perchlorate by adding small amounts of nitroguanidine. Although it appeared that the ammonium perchlorate was detonating at the ideal detonation velocity of the nitroguanidine additive, the effect of confinement was not adequately assessed. In the present work we investigated the variation of detonation velocity and detonation output characteristics of the ammonium perchlorate-nitroguanidine composite, under steel confinement, as functions of charge diameter and the amount of NQ additive. Additionally, most tests were conducted with materials and test devices prepared over one year ago and compared to freshly prepared materials and devices.

1. INTRODUCTION

In previous work (1,2,3) we have investigated the achievement of stable sympathetic detonation of insensitive explosive materials such as ammonium perchlorate (AP) by sensitizing the latter with small amounts of nitroguanidine (NQ). As Figure 1 illustrates, AP itself can detonate but requires rather large critical diameters and is affected by factors such as particle size. (4) Although our work is not restricted to the NQ-AP composite system, the choice of this combination was predicated on the fact that both materials were purported to be Group II type explosives; i.e., explosives that have a decreasing critical diameter with decreasing density. The contrasting behavior (5) of composite explosives and molecular explosives has demonstrated that generally composite, heterogeneous fuel-oxidizer mixtures behave as Group II explosives whereas molecular explosives have the more typical increasing critical diameter with decreasing loading density. Further work in this area had indicated that some molecular explosives, including NQ, also behave as Group II explosives. (6) However, subsequent investigation of the behavior of NQ indicated that the matter was more complex, involving both a low-bulk and high-bulk NQ and that, in the density ranges investigated, NQ was more typically a Group I explosive. (7) Nevertheless, in our investigations, which involved NQ at loading densities much below those investigated elsewhere, the use of NQ for the purpose stated was most successful. In our recently reported work (3) we demonstrated that small amounts, e.g. to 1 percent or less, of NQ in AP would achieve sympathetic detonation of the AP at or near the ideal detonation velocity of the NQ component, based on its actual loading density. We achieved detonation of confined NQ-AP composites at charge diameters of 0.6 cm where the detonation velocity was near ideal for the NQ component, below 0.1 gm/cc. In larger, practically unconfined charges of 4 cm diameter the detonation velocity was again near ideal for the NQ component, in this case nearly 0.01 gm/cc or possibly lower.

However, although the results confirmed that the AP was detonating apparently independent of its own density and moderate confinement, a major question arose: what was the effect of confinement at larger charge diameters, where the AP itself might begin to undergo non-ideal detonation? It was therefore the purpose of the work reported here to assess the effect of confinement and charge diameter on the detonation velocity and detonation output of AP sensitized with variable amounts of NQ.

2. EXPERIMENTAL

The theoretical and experimental aspects of these investigations have been described previously. (3) The specific experimental device utilized for the work that is reported in this paper is illustrated in Figure 2. Two parameters were evaluated; the charge diameter and the NQ component amount. Both were evaluated at 3 levels, as follows: (1) charge diameter; nominal pipe sizes of 0.25, 0.75, and 1.50 in. for specific charge diameters of 0.9, 2.1, and 4.1 cm and, (2) NQ component percentage; 5, 2.5, and 1.25 percent by weight. The bulk densities of these NQ-AP composites remained about the same at approximately 1.3 gm/cc. Although the slight variances of bulk densities were considered for specific calculations, the variations were considered inconsequential for overall effect. A full factorial of 9 tests was conducted.

These charges were prepared and loaded and then stored for over one year before testing. As a consequence, due to the loss of 2 test records these 2 tests were repeated with freshly prepared materials. The detonation velocity record was lost in one test and the film record was lost in the other test. Thus these repeat tests not only made up for the lost records in each case but replicated the detonation velocity in one case and the film record in the other.

As in earlier work, fiber optic probes in conjunction with light detectors at 6 stations were utilized to determine the detonation velocity. To assess the detonation output we utilized a combined approach of utilizing aluminum witness cylinders to assess pressure output by depth-of-dent technique and determined the velocity of the projected witness cylinders. The velocity was obtained by photographing the projected witness cylinder with a Fastax camera as it passed two fiducial markers set 0.6 m (2 ft) apart. The depth-of-dent technique, due to experimental problems that included spallation, distortion (metal flow), and impact damage as the high-velocity cylinders impacted a steel back-up plate, were strictly qualitative. We had previously assessed detonation pressures directly utilizing carbon resistor pressure gauges [3] fashioned after the original technique developed at the Bureau of Mines.[8,9] In the tests reported here we could not accomodate both the pressure gauges and the use of a projectile witness cylinder because of interaction between the two. Since in these experiments we were more interested in the damage and velocity imparted to the cylinders we dispensed with the pressure gauges. The major objective of these tests was to assess the variation of detonation velocity as a function of charge diameter.

3. RESULTS

The experimental test data and results of the experiments are presented in Table 1. As was stated earlier, in Test No. 5 the detonation velocity record was lost but the film record resulted in a projectile velocity of 180 m/sec. The repeated Test No. 11 provided the detonation velocity record but additionally replicated the projectile velocity - 173 m/sec, certainly within experimental accuracy, particularly since Test No. 5 had a slightly higher bulk density. Similarly in Test No. 9 the film record was lost but the detonation velocity was measured at 1.61 mm/μsec. The repeat Test No. 10 provided the film record for projectile velocity but additionally replicated the detonation velocity measurement - 1.55 mm/μsec, again certainly within experimental accuracy, particularly since Test No. 9 had a higher bulk density, hence a slightly higher NQ loading density. Note that without further consideration the trend is already obvious; the detonation velocity increases as the charge diameter increases, but the effect becomes less pronounced as the NQ percentage diminishes. Similarly the projectile velocities seem to approach specific values as the NQ component percentage diminishes. Increased detonation velocity of the composites, due to combined or possibly synergistic effects of sympathetic detonation of the AP and initiation of non-ideal detonation of the AP is evidently taking place.

This can be better illustrated in Table 2. In tests at small charge diameters (Tests Nos. 2, 9, and 10) the detonation velocity measured is, practically, the ideal detonation velocity of the NQ component. In tests at larger charge diameters (Tests Nos. 3, 7, and 8) the detonation velocity measured is about 9, 8, and 5 percent greater for the 5, 2.5, and 1.25 NQ component percentages, respectively; i.e., deviating more as the NQ component percentage increases. In tests at the largest charge diameters (Tests Nos. 4, 11, and 6) the detonation velocity measured is about 33, 15, and 13 percent greater for the 5, 2.5, and 1.25 NQ component percentages, respectively, deviating even more than in the 0.75 in. pipes. The 2.25 mm/μsec detonation velocity in Test No. 4, with 5 percent NQ and a charge diameter of 4.1 cm, is an increase of 33 percent above ideal based on the NQ component. The ideal detonation velocity for the AP component of this composite would be 4.18 mm/μsec [4] if the AP itself would detonate. Thus, either or both increasing the charge diameter or the NQ component percentage increases the potential of confined NQ-AP composites to enter the non-ideal detonation regime of AP with the possibility of achieving ideal AP detonation. Of course, the particle size of the AP would also be effective in achieving higher detonation velocities based on work reported on the detonation of AP.[4]

Another aspect of this work has been to assess the detonation output characteristics of these NQ-AP composites as pertains to imparting kinetic energy to the cylinders in contact with the explosive and to obtain some determination of the corresponding amount of damage to the cylinders. In work conducted previously to assess the explosive projection of materials [11] we established a correlation of the material velocity with its ratio of cross-sectional area subject to the explosive forces over mass, designated as Ax/m. In the work reported here the area of concern was the effective explosive contact area against the flat surface of the cylinders. Table 3 illustrates calculations based on this type of analysis.

A most interesting result of these experiments was that the depth-of-dent or damage assessed did not relate to the projectile velocity. The worst case was Test No. 4, where the 2.5 in diam by 1 in. thick cylinder spalled, and where the resultant dimensions were about 4 in. diam. by 0.125 in. thick. Yet the velocity was not significantly higher than for the comparable tests in 1.50 in. diam. pipes at 2.5 and 1.25 percent NQ. Figure 3 illustrates the relative physical damage to these cylinders. Cylinders from tests in the 0.75 in. diam. pipes were not badly distorted; however, the dent depths were 5.6, 4.0, and 2.8 mm, respectively, for the 5, 2.5, and 1.25 percent NQ systems, indicating considerable variation in detonation (shock) pressure upon the cylinders.

Table 4 presents data and calculations correlating the detonation velocity, which we can use in lieu of the product gas particle velocity here as AP is nearly the total source of energy and the bulk densities are nearly identical. Therefore considering the kinetic energy of the product gases to achieve the attained velocities, we have the constants in the last column in Table 4, which differ for each pipe size because of the area upon which the force acts and the mass of the cylinder. The value obtained in Test No. 4 deviates from the values of Tests Nos. 11 and 6 considerably. It is likely that the spalling in that test resulted in a lower velocity or some other limiting effect caused a lower value. Whatever the reason, if we delete this value and average the others we have the following results:

- 7.4 for the nominal 0.25 in. pipe
- 13.4 for the nominal 0.75 in. pipe
- 55.7 for the nominal 1.50 in. pipe

The Ax/m values for these tests are:

- 0.84 for the nominal 0.25 in. pipe
- 1.57 for the nominal 0.75 in. pipe
- 5.94 for the nominal 1.50 in. pipe

To obtain a constant we divide the first value by the second and obtain:

- 8.8 for the nominal 0.25 in. pipe
- 8.5 for the nominal 0.75 in. pipe
- 9.4 for the nominal 1.50 in. pipe

This constant is 8.9 ± 0.3 or about 3 percent accurate for all the tests, exclusive of the deleted Test No. 4. This is very strong evidence that to obtain optimum explosive projection of materials with a minimum of damage it is desireable to reduce the detonation pressure as much as possible yet maintain a high detonation (gas flow) velocity. This is basically the reasoning in our work on utilizing very low density explosives for the explosives dissemination of projectiles.[1,3,11,12,13,14]

4. SUMMARY

In this work we evaluated the effect of confinement and variations in charge diameter and NQ component percentages in composite NQ-AP systems. We had previously shown that with as little as 1 or 2 percent NQ in AP we could achieve sympathetic detonation of the AP which depended on the detonation velocity of the actual NQ loading density. The objective was to achieve stable, propagating detonation in small diameter charges; e.g., 0.6 cm diam. However, in later work we utilized this system at much higher charge diameters. The concern was when and to what extent increased charge diameter, particularly in confined charges, would cause non-ideal if not ideal detonation of the AP itself or to what extent these conditions acted, in synergistic fashion perhaps, to deviate considerably from the NQ controlled sympathetic detonation of the AP.

Our results indicated that at low charge diameters, e.g. about 1 cm, the NQ evidently was in complete control. However, as the amount of NQ increased and/or the charge diameter increased, the detonation velocity in confined charges began to deviate, increasing possibly into the non-ideal or induced non-ideal detonation regime of the AP. In reality the overall effect is probably more complex, involving interaction between the NQ and the AP. At charge diameters of about 4 cm there exists considerable deviation from the NQ detonation velocity control and it is conceivable that, with even greater confinement, smaller AP particle sizes, or other factors the AP could go into ideal AP detonation.

In another aspect of this evaluation the detonation output characteristics were assessed for damage and kinetic energy imparted into aluminum cylinders in contact with the explosive compositions. Here it was shown, in accordance with our previous investigations, that high detonation pressures lead to extensive damage whereas high detonation (gas flow) velocities lead to the achievement of high velocities.

Finally, the majority of these tests were conducted with materials and test hardware prepared more than a year ago. With the exception of one test, with NQ at 1.25% in nominal 0.25 in. pipe, which failed to propagate (later examination indicated the NQ-AP had caked), all tests functioned as well as freshly prepared materials and hardware.

Table 1

EXPERIMENTAL TEST DATA AND RESULTS FOR NQ-AP COMPOSITES CONFINED IN STEEL PIPES

Test No.	NQ % by wt	Bulk Density gm/cc	Pipe Size nom. in. diam.	Storage >1 year	Detonation Velocity mm/μsec	Projectile Velocity m/sec
2	5	1.30	0.25	yes	1.70	21
3	5	1.24	0.75	yes	1.84	45
4	5	1.25	1.50	yes	2.25	193
9	2.5	1.44	0.25	yes	1.61	lost
10	2.5	1.32	0.25	no	1.55	18
7	2.5	1.29	0.75	yes	1.69	39
5	2.5	1.24	1.50	yes	lost	180
11	2.5	1.19	1.50	no	1.79	173
-	1.25	caked	0.25	yes	failed	-
8	1.25	1.27	0.75	yes	1.57	33
6	1.25	1.26	1.50	yes	1.69	164

Table 2

PIPE SIZE EFFECT ON DETONATION VELOCITY FOR NQ-AP COMPOSITES

Test No.	Pipe Size nom. in.	NQ % by wt	Detonation Velocity, mm/μsec ideal**	actual	ratio actual/ideal
2	0.25	5	1.70	1.70	1.00
3	0.75	5	1.69	1.84	1.09
4	1.50	5	1.69	2.25	1.33
9	0.25	2.5	1.58	1.61	1.02
10*	0.25	2.5	1.57	1.55	0.99
7	0.75	2.5	1.57	1.69	1.08
11*	1.50	2.5	1.56	1.79	1.15
8	0.75	1.25	1.50	1.57	1.05
6	1.50	1.25	1.50	1.69	1.13

*Fresh prepared tests; all others prepared and stored for over one year prior to testing.

**Based on the equation $D = 4.015\ \rho + 1.44$ for NQ.[10]

Table 3

CORRELATION OF PROJECTILE VELOCITY WITH Ax/m*

Test No.	Pipe Size nom. in.	Projectile Velocity m/sec	Ax/m mm^2/gm	Projectile Velocity / Ax/m
2	0.25	21	0.84	25
3	0.75	45	1.57	29
4	1.50	193	5.94	32
9	0.25	lost	0.84	-
10	0.25	18	0.84	21
7	0.75	39	1.57	25
5	1.50	180	5.94	30
11	1.50	173	5.94	29
8	0.75	33	1.57	21
6	1.50	164	5.94	28

*Ax/m is the ratio of the explosive contact area with the surface of the cylinder witness item divided by its mass; the mass of the items used was 80 gm for the 0.25 in. pipe tests and 220 gm for the 0.75 and 1.50 in. pipe tests, measuring physically 1.5 in. diam and 2.5 in. diam, respectively, 1 in. deep in all cases.

Table 4

CORRELATION OF PROJECTILE VELOCITY WITH DETONATION VELOCITY

Test No.	Pipe Size nom. in.	NQ %	Detonation Velocity mm/μsec	Projectile Velocity m/sec	Projectile Velocity / $(\text{Detonation Velocity})^2$
2	.25	5	1.70	21	7.2
10	.25	2.5	1.55	18	7.5
3	.75	5	1.84	45	13.3
7	.75	2.5	1.69	39	13.6
8	.75	1.25	1.57	33	13.4
4	1.50	5	2.25	193	38.1
11	1.50	2.5	1.79	173	54.0
6	1.50	1.25	1.69	164	57.4

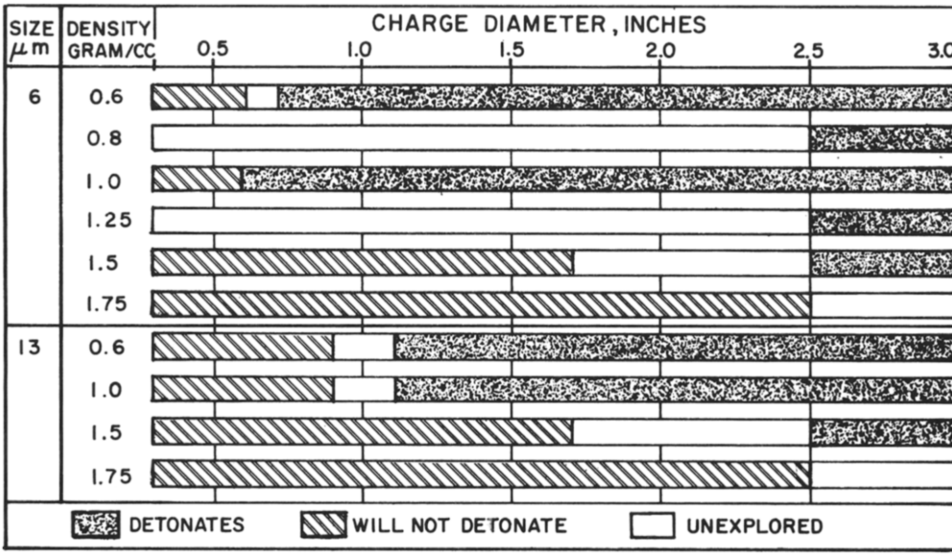


Fig. 1. EFFECT OF PARTICLE SIZE AND LOADING DENSITY ON THE CRITICAL DIAMETER OF AMMONIUM PERCHLORATE. (4)

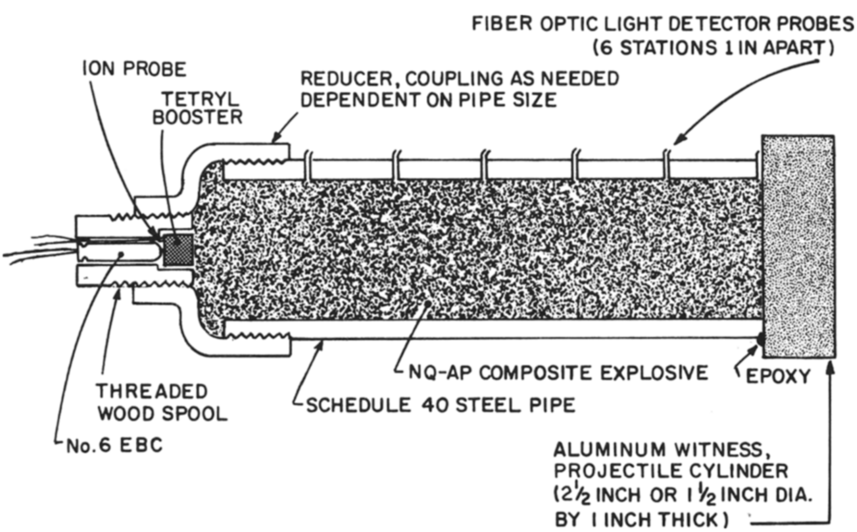
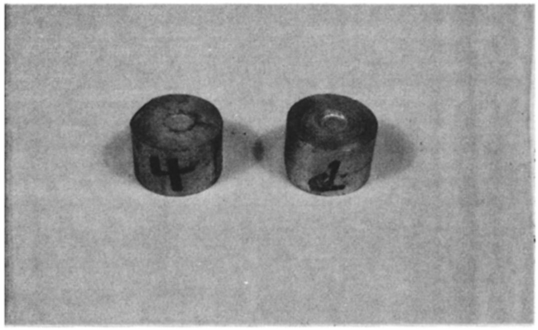
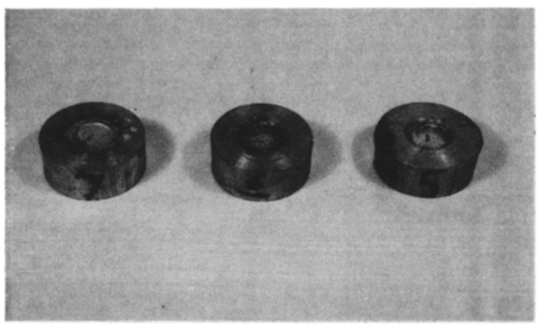


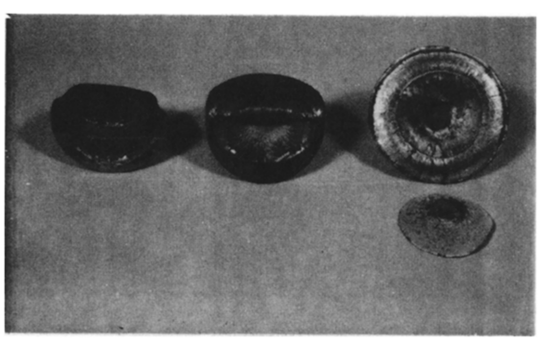
Fig. 2. EXPERIMENTAL TEST ITEM UTILIZED TO ASSESS EFFECTS OF CHARGE DIAMETER AND AMOUNT OF NITROGUANIDINE ON CONFINED CHARGES OF NQ-AP.



0.25 in. diam. pipe
2.5% NQ left, 5% NQ right



0.75 in. diam. pipe
1.25% NQ left, 2.5% NQ middle, 5% NQ right



1.50 in. diam. pipe
1.25% NQ left, 2.5% NQ middle, 5% NQ right

(Note: Numbers on test items are <u>not</u> test numbers.)

Fig. 3. DENTS AND DAMAGE TO WITNESS/PROJECTILE CYLINDERS

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