Applying Explosives Testing Techniques To Obtain Insight into the Explosion (Or Is It Detonation?) Phenomenon of Piles of Fireworks

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ABSTRACT

There are times when the legal system requires so-called expert witnesses. Whether it is with regard to terrorist or criminal activities or accidents, the expert is often confronted with explaining the dreaded term "detonation". The attempt to explain such a catastrophic event often brings about the use of similes. In this paper, the author will provide arguments to support the use of a modified Height-to-Detonation and other steel pipe tests to generate data that may be useful in differentiating explosive reactions, including detonation, within a pile of fireworks. Work continues in this vein and test results will be published in a future article.[1]

Keywords: explosion, detonation, aerial shell, height to detonation output testing

Introduction

What is the duration of the explosion of a pressure vessel? Similarly, what is the duration of a dust explosion in a 500 m coalmine shaft? What is the duration of an explosion of a 500 m long pipe filled with natural gas? How long does it take from ignition to total consumption of 1 kg of Black Powder? How long does it take to totally consume a stick of dynamite from the time that the detonator is functioned? To many, these events are all "instantaneous" or that "they" explode "en masse". That is, they happen so quickly that for most, the duration of these events is too short to measure and therefore is deemed to be instantaneous. However, if one habitually measures in the region of femtoseconds (10^{-15} s), as in high-energy physics interactions, then the above events are of fairly long duration and far from being instantaneous.

How, then, does one explain that the explosion of a pressure vessel is different from the explosion of a pile of fireworks, is different from the explosion of a pile of pyrotechnic compositions, is different from the explosion of a pile of propellant, is different from the explosion of a pile of ANFO, or is different from the explosion of a pile of HMX? Should one be satisfied to state that all these explosions are the same because they are "perceived" to be instantaneous or that some are different because they don't simply explode but "detonate"? Or, is all that matters, is the simultaneity of the event as perceived by the human ear?

Energetic materials are often characterized through a measure of their output, including their rate of reaction, (velocity of detonation) and their power (TNT equivalency). As examples, see references 2–6, which deal with the output of fireworks shells and pyrotechnic compositions, TNT equivalency, relative effectiveness and blast pressure. One must recognize that a major parameter effecting the output of an energetic material is its "packaging". This can take the form of simple packaging used in shipping the material, a pipe used in the manufacture of a pipe bomb for increasing the material's damaging effects, and/or the casing of fireworks shells used to deliver the designed effect. Reference 7 contains more rigorous arguments and theory related to these topics.

Evaluation Tests

This paper suggests that a series of tests could be performed to obtain information on the behaviour of fireworks shells when subjected to thermal and blast stimuli. These tests can include *unconfined burns, height-to-detonation tests,* and *open and closed end pipe tests.*

Unconfined Burns

Unconfined burn trials are very common and are typically used to determine if a transition can occur from burning to explosion by varying the heat source and/or the size of sample. Data based on these tests will be the subject of a future paper.

Ideally, the plan would be to form hemispherical piles of firework shells on level ground with an ignition source located on the ground at the centre of the pile. The tests would be instrumented with continuous velocity of detonation probes radiating from the ignition source to various points on the surface of the hemisphere. On ignition, if the pile explodes, the probes would measure a reaction rate. To improve the probability of a reaction, the size and the bulk density of the pile would be increased. Additionally, blast pressures can be used to establish a TNT equivalency if the pile were to explode.

A modification of these hemispherical burns would be performed in large diameter, construction cardboard tubes, which could be filled with various sizes of shells or Roman candles. They would be initiated by flame at their base.

Height-to-Detonation

The less common test, the Height-to-Detonation (HtD) test, makes use of steel pipes with a sealed bottom. The test requires a series of pipes with different diameters and lengths. In the test, a pipe is set vertically to simulate a cylindrical core taken vertically within a conical pile of energetic material. Given this conical pile, the height of the core would increase as one moves from the edge to the center of the pile. See Figure 1.

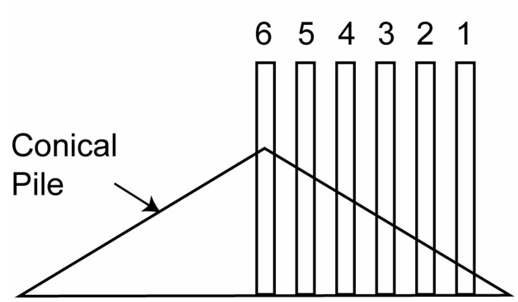

Figure 1. Showing how the height of the sample in the pipe would increase as it moved from the edge of the pile toward the center.

Assuming an ignition source at the bottom of the core, then the confining effect from the mass of the energetic material increases as the height of the core increases. The radial confinement is mostly due to the pipe wall. Increasing the diameter of the pipe/core will ensure that tests are performed in the region of the critical diameter of the energetic material under test, given the confining effect of the pipe. (Note that the wall thickness of the pipe will also play a role.) Ignition takes place at the bottom of the pipe, usually using an ignition source such as Black Powder. The pipe diameter and the height of the material under test are varied, altering the static pressure and the inertial resistance to the combustion products, until an ignition-to-detonation (explosion?) occurs.

The HtD test is often used to evaluate hazards in propellant processing.[8–10] Propellants are quite sensitive to confinement, therefore, it is important to know what amounts and/or thicknesses can be safely manipulated. To prevent catastrophic events, the amount and/or thickness of the propellant being handled should be less than a critical amount as determined in the HtD test performed with a relevant ignition source.

Conical piles of pyrotechnic compositions may be common in a process and the HtD test with a relevant ignition source can be relevant in establishing the safe size of a pyrotechnic composition. Firework articles and more specifically, fireworks shells may also be found in piles in factories and at display sites. Can the HtD be used to establish a safe limit below which an ignition would not result in what is perceived to be an explosion "en masse" or a "detonation"?

Figure 2 shows the set-up for a HtD test where the internal heat source normally used in these tests has been replaced with an external diesel fuel fire in a steel pan below the pipe.[11] (In this case, the modification to the standard

Figure 2. Height-to-Detonation test configuration.

test was made to better reflect the conditions at an accident site.) The external fire represents a relatively slow thermal stimulus requiring a period of minutes to raise the temperature of the energetic material. In contrast, the internal ignition method produces an extremely rapid heat source of short duration.

In this example, the HtD tests were performed by suspending different-sized pipes, with varying amounts of ANFO, approximately 50 cm above the burning pan of diesel fuel. HtD tests were performed to simulate the internal ignition of piles of ANFO with heights up to three metres. Typical instrumentation included three thermocouples within the pipe at 2.5, 15, and 45 cm from the base. See reference 11 for further details.

An example of the data obtained on ANFO[11] from thermocouples located at the bottom section of the pipe is shown in Figure 3. Typically, a mild decomposition begins, producing white smoke that then accelerates to eject most of the mass from the pipe. The reaction often ended with mild "popping" sounds, possibly due to the ignition of flammable gases escaping from the top of the pipe. The thermogram of Figure 3 indicates the characteristic ammonium nitrate (AN) phase change temperatures, specifically, those at 32 and 84 °C. Other higher peaks are in the neighbourhood of the melting and the decomposition temperatures of AN.

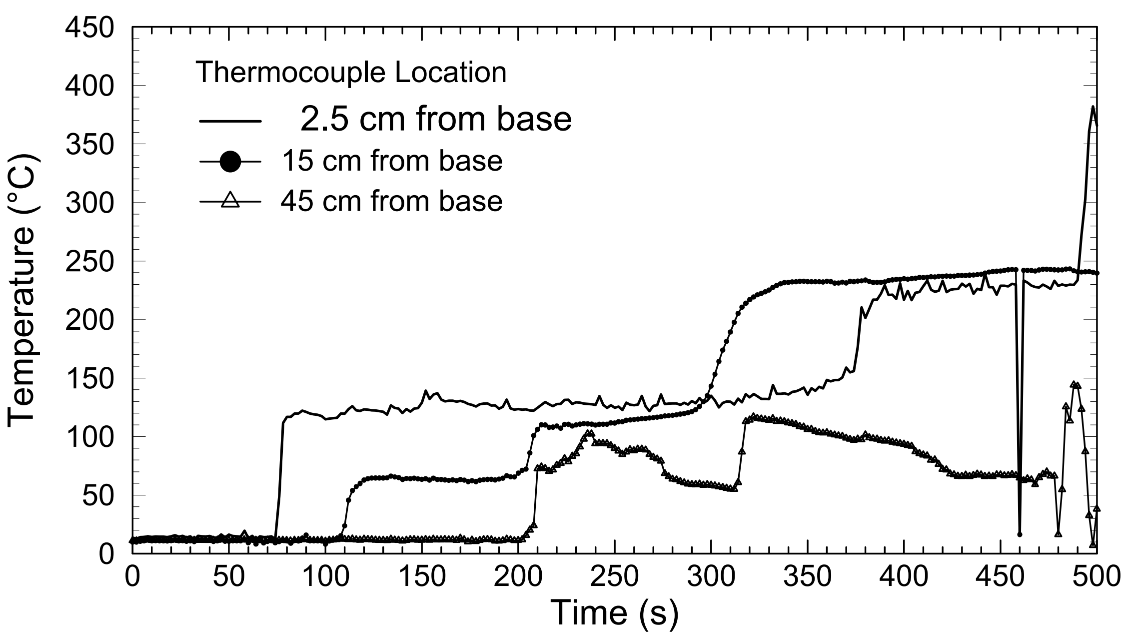

Figure 3. Details of the first 400 seconds of temperature profiles for HtD Test 5.

Figure 4. Preparation of plastic shells (no lift charge). Note steel pipe at top right of photo.

These series of HtD tests with ANFO indicated that it is unlikely that a pile of this explosive, under normal conditions, can provide the confinement required to lead to a detonation. The 3 m maximum test height was insufficient to cause a transition to explosion. It is possible that a taller pile of ANFO, with more confinement and/or a more energetic stimulus, could result in the transition.

If one were to perform HtD tests in this configuration with fireworks shells, (the fit being the same as with shells in standard mortars), the fire would heat the pipe and cause immediate initiation of the lift charge of the shells in the hot area (lower end of the pipe). The flame from the lift charge from these shells would not only ignite their respective delay elements but would jet by their respective shells to possibly ignite shells further up the column. However, with initiation occurring at the base of this closed-end, 3 m long, HtD pipe, it is very unlikely that the ignition of the lift charge of the shells in this region will be able to propel the column of shells out of the pipe. The lack of movement in the bottom shells will result in such high pressures that the shell or shells in this region will explode and burst the length of pipe in their vicinity. Additionally, if flames from the lift charge(s) traveled sufficiently far in the clearance volume between the column of shells and the inside wall of the pipe, the uppermost shell or shells could be ejected out of the open end of the pipe.

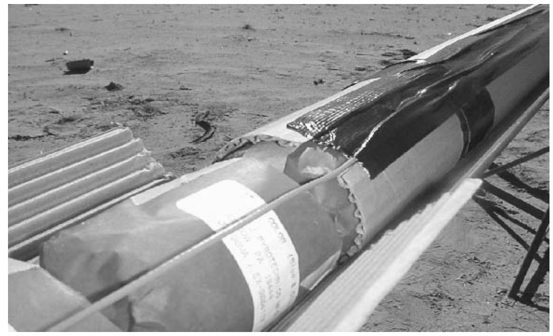

Figure 5. Shells (with lift charge) being wrapped in cardboard. Note velocity of detonation probe cable along shell surface.

Pipe Tests

Pipe tests are often used to determine the effect of confinement on the reaction rate and/or detonation velocity of energetic materials. The containment parameters include the pipe material (most commonly steel), diameter, and wall thickness. The length is usually fixed to a predetermined value. The pipe ends are either capped or left open, and the pipe may be either partially or completely filled with the test material. The tests performed in a pipe with one closed and one open end will simulate the HtD tests.

At this stage of the test program, some tests have been performed with nominal 1 and 3 m lengths of pipe filled with fireworks shells and Roman candles. Different pipe diameters will be used to accommodate shells up to 305 mm (12 in.). Figures 4 and 5 show two different shells being prepared for insertion into a steel pipe.

The fireworks shells were initiated with different stimuli. Electric matches were usually, simply inserted into the lift charge of the first shell. To initiate those shells with lift charge removed, a separate Black Powder charge was prepared with an electric match. Also, tests will be performed with explosive boosters to overdrive the initiation process. A resistive cable will be used to witness the reaction rate of the fireworks shells within the pipe and high-speed video will track the event. In case of an explosion, the pipe fragments and surviving shells will be recovered. The fragments will be used to classify the explosion and relate it to a detonation event.

Conclusions

In Reference 1, details of the tests being performed will discuss results such as the type and size of fragments produced from fireworks stars and fireworks shells caused to burst in steel pipes. Also, the reaction rates, as measured with velocity of detonation probes will be presented as a means to elucidate the mechanism of a pile of fireworks exploding. The data will also reference previous data including tests for classifying explosives[12] to establish a relationship between fireworks explosions and explosives detonations.

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