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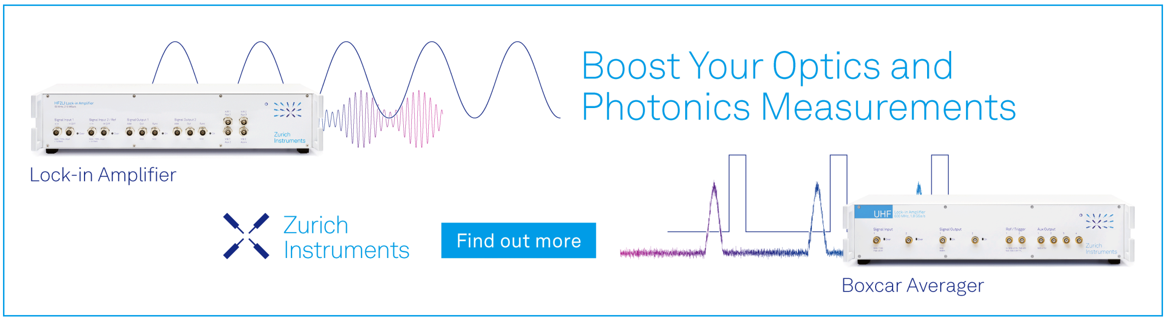

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DETONATION FAILURE CHARACTERIZATION OF NON-IDEAL EXPLOSIVES

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Abstract. Non-ideal explosives are currently poorly characterized, hence limiting the modeling of them. Current characterization requires large-scale testing to obtain steady detonation wave characterization for analysis due to the relatively thick reaction zones. Use of a microwave interferometer applied to small-scale confined transient experiments is being implemented to allow for time resolved characterization of a failing detonation. The microwave interferometer measures the position of a failing detonation wave in a tube that is initiated with a booster charge. Experiments have been performed with ammonium nitrate and various fuel compositions (diesel fuel and mineral oil). It was observed that the failure dynamics are influenced by factors such as chemical composition and confiner thickness. Future work is planned to calibrate models to these small-scale experiments and eventually validate the models with available large scale experiments. This experiment is shown to be repeatable, shows dependence on reactive properties, and can be performed with little required material.

Keywords: Non-ideal explosives, ammonium nitrate, microwave interferometry.
PACS: 47.40.Rs, 07.60.Ly.

INTRODUCTION

Non-ideal explosives have more recently become of interest due to the availability of constituent materials and relatively low-costs, which allow terrorists to obtain and use them. Modeling of non-ideal explosives has seen a rise in significance to aid further work in mitigation and response. However, current models are limited due to the lack of experimental characterization available. This is because of the large-scale experimental setups required and variations in materials used.

Non-ideal explosives are typically described as having much larger reaction zone lengths when compared to ideal explosives. In previous modeling of non-ideal explosives, a reaction zone length of 1 mm was chosen to differentiate between non-ideal and ideal explosives [1]. The large reaction zone lengths also require large critical diameters to sustain a steady detonation for non-ideal explosives. Previous studies found the critical diameter for neat ammonium nitrate (AN) to be 41.2 mm [2].

Previous efforts have been made to allow for steady detonation to occur on a small-scale [3]. However, these experimental characterization techniques are limited. It is the goal of this work to produce a small-scale technique to characterize non-ideal explosives using a detonation.

Microwave interferometry has been previously used to characterize ideal explosives in deflagration-to-detonation transition (DDT) experiments [4]. The same technique has been applied here to non-ideal explosives on a small-scale where the detonation was expected to fail. The failure dynamics were recorded using the microwave interferometer with time resolved

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measurements of detonation front position. Instead of looking at DDT, the failure of an over-driven detonation front was studied as it travelled through a non-ideal explosive.

EXPERIMENTAL PROCEDURE

Non-ideal and ideal explosives were placed inside a 0.635 cm I.D. tube as seen in Fig. 1. Two different tubes of varied thickness and material were used. Thin wall tube experiments employed a 304 stainless steel tube with 0.071 cm wall thickness. The thick wall tube tests used a 1018 steel tube that had a thickness of 3.49 cm. A Teledyne Risi, Inc. RP-502 detonator was used to initiate a detonation front in Primasheet 1000 that was used as the ideal explosive to allow for a steady detonation front to develop before transitioning to the non-ideal explosive. In these experiments 1.9 g of ideal explosive and 2 to 2.5 g of non-ideal explosive were used for each test.

Microwave Interferometry Technique

In order to obtain the position of the detonation front, a Teflon waveguide is used to transmit a reference signal from a 35 GHz microwave interferometer to the sample. The microwave is partially reflected off of the detonation front and returned back through the waveguide to the interferometer. The reflected signal is mixed with the reference signal to develop an interference signal.

The velocity of the detonation front is related to the frequency of the interference signal. Using this relation, the position can be determined using the zero-axis crossing method by

$$P(t) = \frac{\lambda_I n(t)}{2}\,, \tag{1}$$

where P is the position, λ_I is the wavelength of the interference signal through the medium, and n is the number of times the interference signal crosses the zero-axis. This is a modified method from previous work calculating the velocity of shock waves [5]. The spatial resolution is limited to the frequency of the interference signal with this method due to the calculation of the detonation front relying on each zero-crossing.

Higher spatial resolution can be obtained using the quadrature method used in past work [6]. The microwave interferometer outputs the interference signal and a signal that is shifted 90 degrees from the interference signal. The amplitude of both signals are cancelled out and the two signals combined to calculate the position using

$$P(t) = \frac{\lambda_I}{2\pi}\tan^{-1}\frac{V_2(t)}{V_1(t)}\,, \tag{2}$$

where V_1 is the interference signal and V_2 is the 90 degree shifted signal.

Each method required the knowledge of the wavelength of the interference signal for the material. This was calibrated dynamically by using fiber optics at two known locations of the medium.

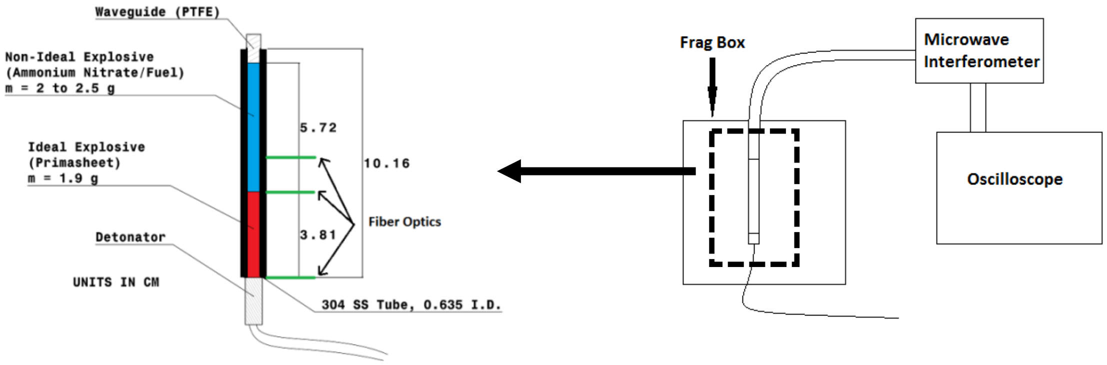

Figure 1. A schematic of the experimental setup using a thin wall tube.

The wavelength is found using

$$\lambda_I = \frac{2L}{N}, \tag{3}$$

where L is the length between the fiber optic and N is the number of times the signal crosses the zero-axis between the time triggered by the fiber optics. The fiber optic setup included a Thorlabs, Inc. M34L02 patch cable with a 600 μm core diameter transmitting to a DET10A photodetector with a 1 ns rise time.

Material Compositions

Experiments were performed using mixtures of AN and various fuel compositions seen in previous work [7]. C-J pressures were predicted for a range of compositions using CHEETAH [8]. Fuels were selected at various compositions to allow for varied C-J pressures. Compositions for investigation were chosen based on the predicted C-J pressure; assuming that the failure dynamics of these non-ideal explosives correlate to the predicted C-J pressures. The non-ideal explosives characterized in this work include 2% (wt.) and 10% (wt.) diesel fuel and 10% (wt.) mineral oil compositions with AN.

RESULTS AND DISCUSSION

Experimental results using diesel fuel as the fuel may be seen in Fig. 2 for thin walled tubes. The right edge of the plot represents a schematic of the tube that the detonation front is traveling through. The horizontal line represents the location in the tube where the detonation front transitions from the ideal to the non-ideal explosive. The portion above and below the horizontal line represents the non-ideal and ideal explosive respectively.

Every experiment utilizes the same length of ideal explosive to develop a steady detonation front. The constant slope seen below 4 cm represents the steady detonation front leading up to the non-ideal explosive. As anticipated, the detonation front begins to decrease in velocity as it transfers to the non-ideal explosive. The results show that for AN/2 wt.% diesel fuel the detonation was sustained for a longer period of time and exhibited a different position trace than AN/10 wt.% diesel. The deceleration of the detonation front to failure was larger for the AN/10 wt.% diesel. It is noted that predictions showed C-J pressure to be larger for AN/2 wt.% compared to AN/10 wt.% diesel fuels. The detonation front velocity slows at a lower rate for AN/2 wt.% than it does for AN/10 wt.% diesel. It is hypothesized that the larger pressure behind the detonation front allows for the reaction zone to sustain the detonation longer, hence resulting in the position trace trends that were measured. The results also show the repeatability of the experimental method of characterizing non-ideal explosives on a small-scale.

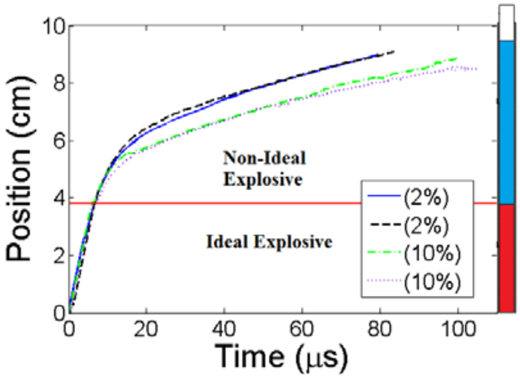

Figure 2. This is a plot of the detonation front position as a function of time for various compositions of diesel fuel in a thin wall tube test setup.

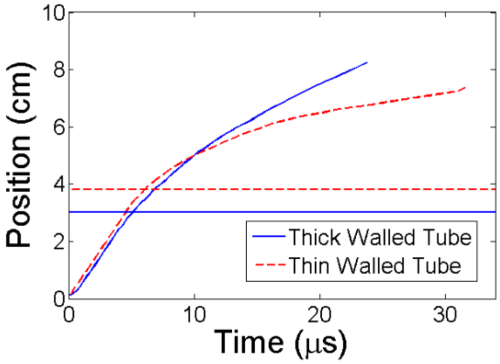

Figure 3. This is a plot of the detonation front position as a function of time for mineral oil using two different tube thicknesses.

Results show that the rate of failure for the detonation front is also different due to the tube thickness, as seen in Fig. 3. The length of ideal explosive in the thick wall tube was 3 cm while the length in the thin wall tube was 3.8 cm. The difference in length is due to slightly different fiber optic port configurations in the thick wall tube. The solid and dashed horizontal lines represent the transition zone to the non-ideal explosive for the thick and thin wall tubes respectively. It is shown in Fig. 3 that the detonation front slows and eventually fails in the thin wall tube sooner than in the thick wall tube. The thick wall tube limits the lateral loss of energy, allowing for the reaction zone to sustain the detonation front more effectively than allowed in the thin wall tube. The thin wall tube allows for higher energy loss through the greater deformation of the tube. Eventually enough energy is lost and the reaction zone can no longer sustain the detonation. The detonation began to fail in the thick wall tube; however it did not fail completely. No recovery of non-ideal explosive in the thick wall tube was made. The detonation front completely failed in the thin wall tube and residual material was recovered.

CONCLUSIONS

A unique method has been developed to characterize the failure dynamics of non-ideal explosives at the small-scale. Experiments have been performed using AN with diesel fuel and mineral oil at various compositions. Results show factors such as chemical composition and confiner thickness affected the detonation failure dynamics.

Thin wall experiments that used 2 wt.% and 10 wt.% diesel as the fuel showed a difference in the rate of failure of the detonation front. The AN/2 wt.% diesel sustained the detonation longer and the rate of the velocity decreasing was smaller. Thin and thick wall tubes used with AN/2 wt.% mineral oil also showed different failure dynamics. The thick tube limits lateral losses of energy much better than the thin tube and sustains the detonation for a longer period of time.

Future experiments with other fuel compositions are planned that include using sugar as a fuel. Current modeling is underway to reproduce the position vs. time traces that have been produced as well. A model that can incorporate the failure dynamics observed in the presented small-scale experiments has the potential to be applied to large-scale experiments for validation. Once validated, these small-scale experiments could be applied to numerous non-ideal explosive compositions very quickly.

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