Combustion and Flame 194 (2018) 271–277

Contents lists available at ScienceDirect

Combustion and Flame

journal homepage: www.elsevier.com/locate/combustflame

Relating a small-scale shock sensitivity experiment to large-scale failure diameter in an aluminized ammonium nitrate non-ideal explosive

Nicholas R. Cummock[a,*], Jesus O. Mares, Jr.[b], Ibrahim E. Gunduz[a], Steven F. Son[a]

[a] School of Mechanical Engineering, Purdue University, West Lafayette, Indiana 47907, USA
[b] School of Aeronautics and Astronautics, Purdue University, West Lafayette, IN 47907, USA

ARTICLE INFO

Article history:
Received 29 December 2017
Revised 7 May 2018
Accepted 7 May 2018

Keywords:
Shock sensitivity
Detonation failure
Ammonium nitrate
Non-ideal
Microwave interferometry

ABSTRACT

The detonation failure process, specifically where a transient reaction occurs in an overdriven explosive due to a sub-critical charge diameter, has remained relatively unexplored, particularly regarding its relationship to shock initiation mechanisms. Detonation failure, here defined as a weakly supported shock wave traveling with a decaying velocity, of aluminized ammonium nitrate (AN/Al) was considered to investigate the relationship between the detonation failure process and shock sensitivity. Previous work has shown that the Al additive particle size alters the failure diameter, a measure of shock sensitivity, of AN/Al. Microwave interferometry was used to measure the transient shock wave velocity in the explosive system, which was lightly confined at a diameter below its critical diameter, in response to an overdriven shock insult in a small-scale experiment. An array of mixture ratios and particle size distributions of the explosive system was used to vary the sensitivity of the explosive and to facilitate exploration of the relationship between the shock velocity decay rate, initiation mechanisms, and large-scale shock sensitivity. Resulting shock velocity profiles in AN/Al indicate that micron-sized and larger Al particles can contribute to the detonation process. It is concluded that the rate at which the transient shock velocity approaches that of a compressive wave with no supporting reaction corresponds to the relative shock sensitivity of the system; it is therefore proposed that the measured shock velocity decay rate of an overdriven sub-critical diameter charge of AN/Al reveals quantifiable information about the relative shock sensitivity of a large-scale charge.

1. Introduction

The failure to achieve a sustained detonation in a shocked detonable material can occur when either the critical initiation energy of the material is unmet via mechanical insult, or when the shocked charge is unable to locally release enough energy in a timescale sufficient to overcome lateral losses due to an insufficient charge diameter [1,2]. The explicit study of this detonation failure process may prove useful in the understanding of shock initiation mechanisms for detonation; however, this process, specifically when the shocked charge is under the critical diameter while the initiation energy is sufficient to induce a detonation, remains relatively unexplored.

When an explosive charge of a diameter less than its critical diameter is shocked, reaction and subsequent heat release may occur within the material for a certain distance following the shock wave due to various initiation mechanisms. However, lateral energy losses dominate this process and the reaction zone that develops behind the leading shock wave is quickly decoupled and a true detonation is never achieved [2,3], i.e., the coupled shock and reaction zone are not at any time self-sustaining. Because such a reaction never reaches a steady-state, this detonation failure process is governed alone by the same physics and mechanisms as the initiation phenomenon, and as such, potential exists for improving the understanding of initiation and shock sensitivity of explosive materials via small-scale experiments with charge diameters below the critical diameter.

The failure of a shock insult to achieve a steady detonation event in explosive materials can be readily observed in small-scale experiments [3–5]. In particular, explosive systems with a long reaction zone may be well suited to study the effects of additives which tailor the shock sensitivity of the system. Ammonium

* Corresponding author at: Purdue University, Chaffee Hall, 500 Allison Rd, West Lafayette, IN 47906, USA.
E-mail address: ncummock@purdue.edu (N.R. Cummock).

https://doi.org/10.1016/j.combustflame.2018.05.009
0010-2180/

nitrate (AN) based explosives are an example of such a system and are considered non-ideal, such that the reaction zone of the fully established detonation is relatively long due to slow or secondary reactions [6–8]. In these explosive systems, AN may be mixed with fuels such as nitromethane, mineral oil, diesel fuel, or aluminum; these mixtures are commonly used for a variety of purposes, including rock blasting [9], recreational firearms targets [10], and in homemade explosives [3]. Due to the wide variety of potential mixture combinations, and typically large critical diameters associated with these explosives, parametric studies of such systems can be difficult in typical lab settings. Specifically, the large charges which are needed to achieve and sustain a fully established detonation result in high costs and increased safety risks. Additionally, the high number of potential compositions comparing mixture proportions, densities, and particle size distributions to fully explore a potential parameter space compounds these issues with large scale experiments. As such, a small-scale experiment to explore and potentially quantify the shock sensitivity of these systems would yield a valuable approach in explosives evaluation.

In work by Janesheski et al. [3], ammonium nitrate was mixed with fuel oils (ANFO) of varying types and mixture ratios. It was observed that detonation failure dynamics in a small-scale experiment were influenced by certain factors such as chemical composition, level of confinement, and initiating shock pressure. Kittell et al. [5] used a similar experiment with ANFO in varying levels of confinement to calibrate a reactive flow model based on the theory of ignition and growth. It was concluded that by measuring shock velocities in heavily confined charges below the critical diameter, parameters of an ignition and growth rate law could be calibrated, allowing predictive modeling of transient shock velocities in two other levels of confinement, which were validated experimentally.

The objective of this work is to investigate the relationship between the detonation failure process of a non-ideal explosive system and its shock sensitivity using a similar experiment to that found in [3–5]; specifically, the shock velocity in a failing detonation is measured with a spatial resolution sufficient to capture the rate at which the shock velocity decays. The shock velocity decay rate is used to draw correlations to initiation mechanisms and large-scale shock sensitivity of the sampled explosive system. Aluminized ammonium nitrate (AN/Al) was chosen as as the explosive system for this small-scale experiment, where AN/Al in a sub-critical diameter configuration is overdriven by a booster and subsequently fails to progress into a detonation event.

2. Experimental methods

2.1. Instrument configuration

Microwave interferometry is an established technique used in the application of propellants and explosives to measure the transient velocity of a reaction front [11,12]. A custom built (Electrodynamic, Albuquerque, NM) microwave interferometer (MI) was used to transmit and collect a 35 GHz signal to and from a test sample via a 6.52 mm Teflon® rod. Each test sample was comprised of a donor explosive (1.9 g of Primasheet 1000) to supply an overdriven shock insult to the receptor explosive (2.2 g of AN based explosive). Each sample was confined within a 304 stainless steel tube (McMaster-Carr®, Product No.: 6100K148) with an inner diameter of 6.52 mm and a wall thickness of 0.71 mm. A RP-502 Economy Exploding BridgeWire (EBW) detonator (Teledyne Risi, Product No.: 188–7410) was used in concert with a FS-62B EBW firing unit (Teledyne Risi) to initiate the donor explosive within the sample. A schematic of the experimental setup is shown in Fig. 1. Two 90° out-of-phase output signals are generated by the quadrature mixer of the MI and recorded using a Tektronix, Inc. digital phosphor oscilloscope model DPO4034 via two low-loss RG412 type coaxial cables (Pasternack, Product No.: ID PE-P195). In order to effectively trigger the recording of the MI output signals, an open loop current sensor (Honeywell, Product No.: CSLA1DJ) was used to detect a change in current in the wire connecting the firing set to the EBW.

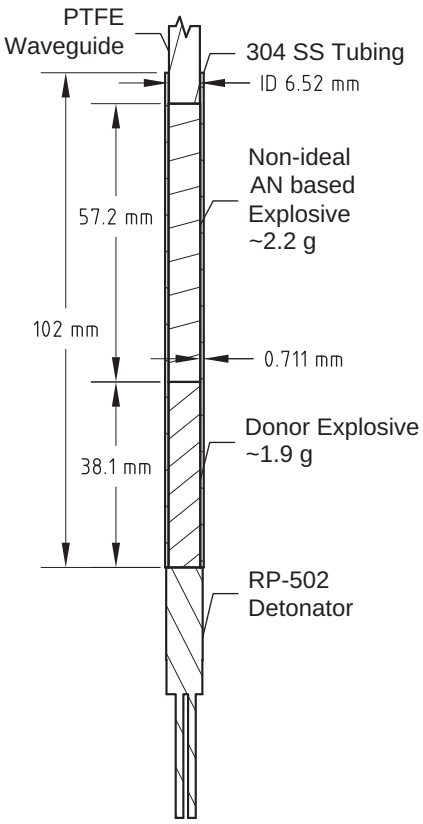

Fig. 1. A typical small-scale test sample, where the RP-502 detonator is connected to a FS-62B Firing Unit, and the Teflon®, i.e., Polytetrafluoroethylene (PTFE), waveguide is connected to the MI.

2.2. Sample preparation

For each sample, the donor explosive was pressed to 98% of its theoretical maximum density (TMD), corresponding to a density of 1.47 g/cm^3. The AN-based receptor explosive consisted of a mixture of AN and various sizes of aluminum particles or inert solid glass beads. The solid glass beads (70% SiO_2, 9.5% Na_2O, 5.8% CaO, 5.7% K_2O, 3.2% BaO) and aluminum particles used in this work have densities of 2.4 g/cm^3 [13] and 2.7 g/cm^3 [14], respectively, and all additives were spherical in shape. Representative images of the smallest and largest Al and glass μbead sizes used in this study are shown in Figs. 2 and 3. Note in Fig. 2(b) and 2(d) the contrast in mixture intimacy due to the difference in Al additive particle size; this difference can also be seen in the glass μbead mixtures in Fig. 3(b) and 3(d). A summary of the materials and sample mixtures is presented in Table 1.

An identifier was given to each mixture (see Table 1) in order to facilitate distinction of fuel and inert additives, as well as the relative size of the additive (see column one of Table 1). In the identifiers, 'Al' and 'G' represent aluminum particles and solid glass μbeads, respectively, and 'S', 'M', and 'L' represent small, medium, and large particle sizes relative to the additive particle sizes used in this study. Each additive listed in Table 1 was combined with ground and sieved (53–106 μm) fertilizer grade AN to make the respective mixture referenced in Table 1. All aluminum and inert additives except for those in Al-S, Al-L, and G-S were sieved to the particle sizes as reported in Table 1; manufacturer