Methodology for Characterizing IM Explosives for Determining Interface Reliability

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Abstract

U.S. Army Research, Development, and Engineering Center (ARDEC) has been transitioning Insensitive Munitions (IM) explosives in Artillery, Mortars, Demo items, Grenades, General Purpose Bombs, etc. Legacy munitions detonation trains relied on small booster inputs due to the small critical diameters and high shock sensitivities of the main fills. Traditional explosive interface testing consists of Go/No-Go tests such as penalty, Bruceton, Langlie, and Neyer tests. IM explosives with larger critical diameters will need a higher sustained pulse in order to properly initiate the main charge. IM explosives require more in-depth techniques to characterize the material. Some of the test data required to parameterize Reactive Flow Models are: cylinder expansion, wedge, corner turning, and cutback testing.

New test methodologies such as the utilization of Photonic Doppler Velocimetry (PDV) have helped to gather more data per test. With the use of multi-channel PDV systems, particle time histories can be collected and used to determine CJ pressure as well as velocity of the explosive material. The objective of this program is to develop an alternative methodology to characterize the reliability of the interface between the fuze initiator and any high explosive IM fill. The following methodology can be used to assess initiator/main fill charge interface reliability: Parameterize Reactive Flow Model(s), feed Reactive Flow Model into Hydro code Model, and use Hydro code Models to evaluate explosive interface design. Any of the following codes can be used for this approach: Lee Tarver Ignition & Growth, CREST, and JWL++.

This paper will discuss the testing necessary to parameterize the Reactive Flow Models for determining initiation reliability of IM explosive fills.

Introduction

The objective of this program is to develop an alternative methodology to characterize the reliability of the interface between the fuze initiator and any high explosive IM fill The following methodology can be used to assess initiator/main fill charge interface reliability: Parameterize Reactive Flow Model feed Reactive Flow Model (RFM) into

Hydrocode Model, and use Hydrocode Model to evaluate explosive interface design as shown in Figure 1.

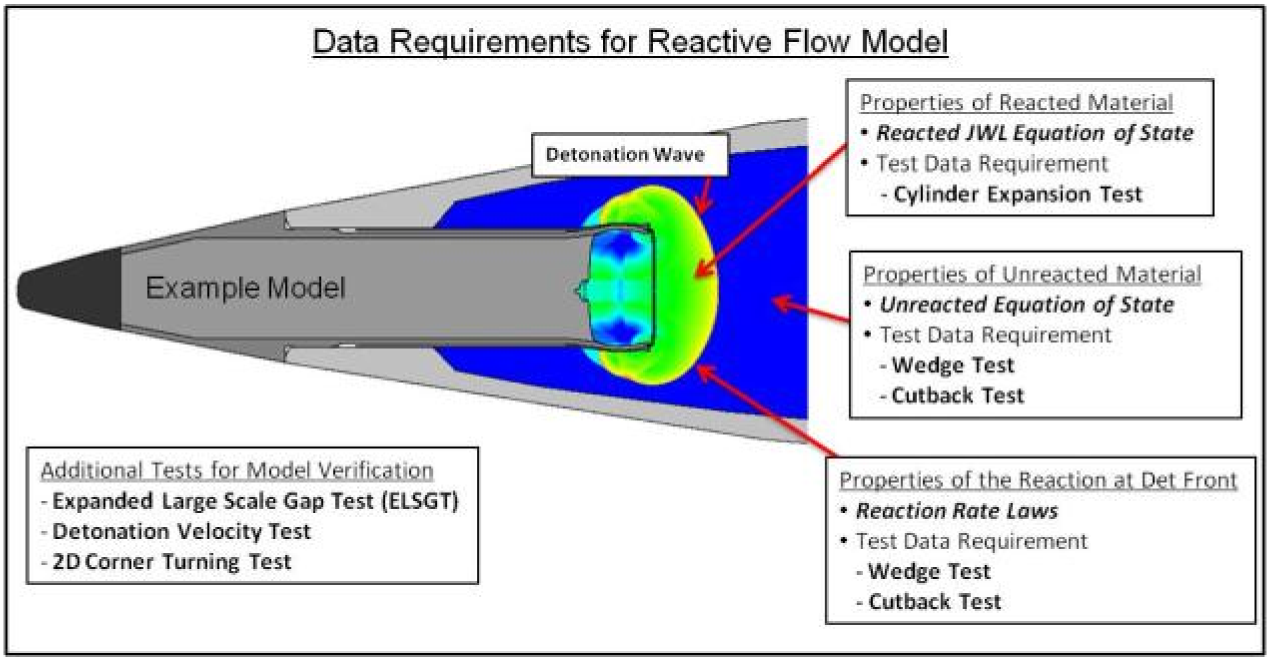

Figure 1. Data Requirements for Reactive Flow Model

Unconfined Detonation Velocity and Critical Diameter Tests

Unconfined detonation velocity tests are performed at various diameters and lengths to determine the critical diameter of the energetic material. Instrumentation such as piezo electric pins, Photonic Doppler Velocimetry (PDV), or streak cameras are typically used to collect data. The results are used to validate the RFM. The length of unconfined material should be long enough for detonation to reach steady state. With IM formulations with large critical diameters, it is even more important to use more than the historical 4 times the diameter approximation for length of the test billet. Recent testing on an IM explosive used a diameter of inches by inches in length with piezo pins located on the Comp B booster all the way to the bottom of the charge as shown in figure 2.

Figure 2. Rate stick setup with piezo electric pins and witness plate block

Cylinder Expansion Test

The cylinder expansion (Cylex) test was performed to determine the reacted equation of state (EOS). This test provides the gurney energy and explosive performance up to seven volumes of expansion. The explosive is detonated while enclosed in a copper cylinder (half inch to four inches in diameter) as shown in figure 3. The resultant expanding wall velocities are recorded with a streak camera as shown in figure 4.

Figure 3. Four Inch Diameter Cylinder Expansion Test Setup

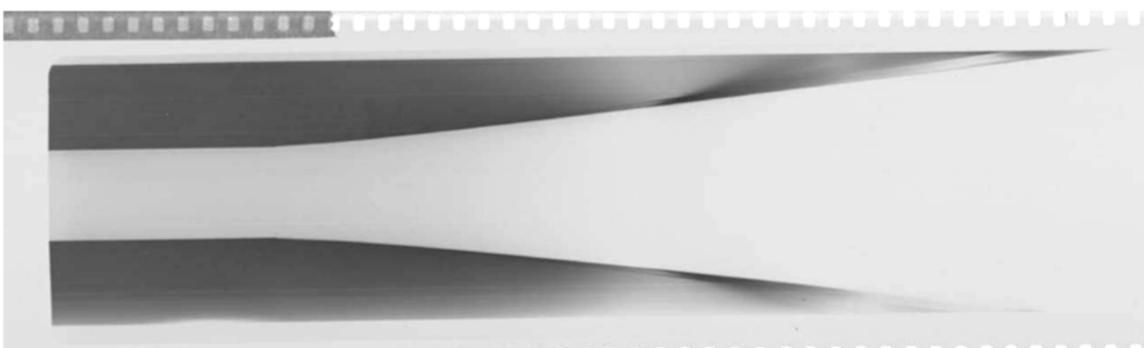

Figure 4. Example of Streak Image from Cylinder Test

Wedge Test

The wedge test is used to determine the shock initiation characteristics of an energetic material. The wedge test "stack up" (figure 5) consists of a plane wave lens, a booster pad or disk of explosive, one or multiple attenuator plates, and a wedged-shaped explosive sample. First, a plane wave lens (PWL) was used to simultaneously initiate the face of a creamed TNT booster pad. Second, detonation of the booster pad further increases the shock wave energy transferred into the attenuator plates. Third, the attenuator plate(s) decrease the pressure of the shock wave that travels into the wedge sample. The thickness, type, and number of plates determine the amount of attenuation.

Finally, the shock wave enters the wedge sample. If it is strong enough, the shock wave will transition into a detonation. The streak camera record from the test shows the arrival time of the shock wave or detonation at the wedge surface (see figure 6).[1]

Wedge Samples

The wedge test samples were made in two steps. First, the samples were cast into billets. Second, the samples were machined to shape with a milling machine. Wider width samples allow for a longer run distance to be obtained. In most tests, in order to achieve the best streak camera records, the wedge surface facing the camera should be painted with polyurethane glue in order to increase surface reflectivity and to fill in surface voids. The recommended geometric wedge angle is about 23 degrees. Radiographs for the wedge samples should look for shrink porosity and voids.

Test Assembly

Two methods can be used to attach the parts of the wedge test "stack up". In one method, the wedge sample can be glued to the attenuator plate. In the other method, a thin layer of vacuum grease can be placed on the interfaces. "Dabs" of glue at the interface edges hold the parts together.

Instrumentation

In the wedge tests, PDV, streak camera, and manganin pressure gauges can be used to determine input pressures and run to detonation. PDV can be used to measure the free surface velocity of the buffer plate. A Cordin streak camera can be used to record the arrival of the shock or detonation wave along a line centered on the wedge surface. A large argon bomb can be used to illuminate the sample.

Data Analysis

For a wedge test, the key piece of information is the arrival time of the shock or detonation wave on wedge surface points for a particular input pressure. This surface information can be used to find the trajectory (x-t) of the shock and/or detonation wave as it travels up into the wedge sample. The x-t curves can then be differentiated to get wave velocity (U)-time (t) or wave velocity-distance (x) curves. Both the run time (t*) and the run distance (X*) where a shock wave turns into a detonation can be found from the inspection of the x-t curve, or both U-t and U-x curves.[1,2]

The results of a series of wedge tests are usually presented as plots of input pressure versus distance to detonation and time to detonation (Pop-plots). With these plots energetic materials may be compared with regard to relative sensitivity. This is done by assuming that for a given distance to detonation, the energetic material that requires the lower input pressure to achieve this distance is the more sensitive.

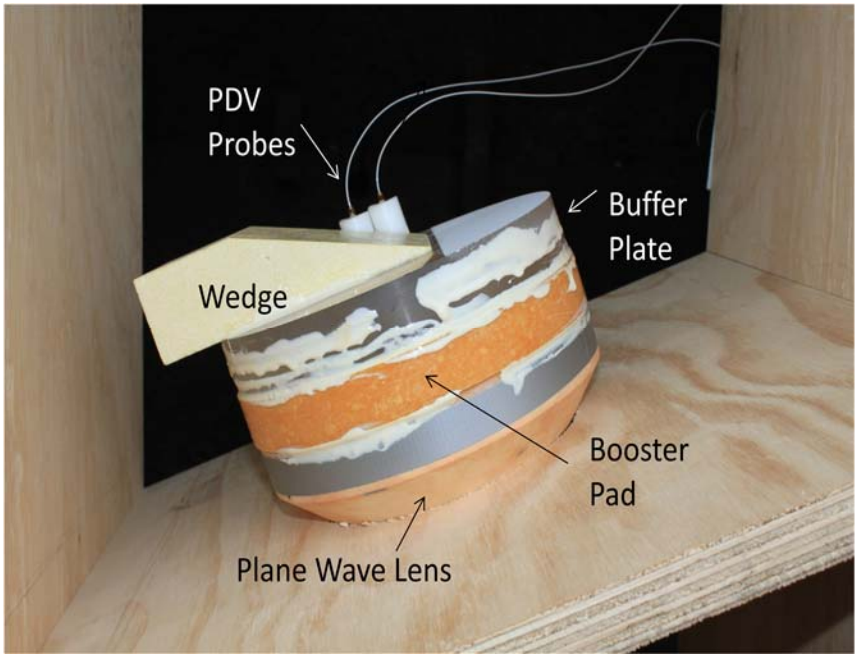

Figure 5. Wedge test set-up

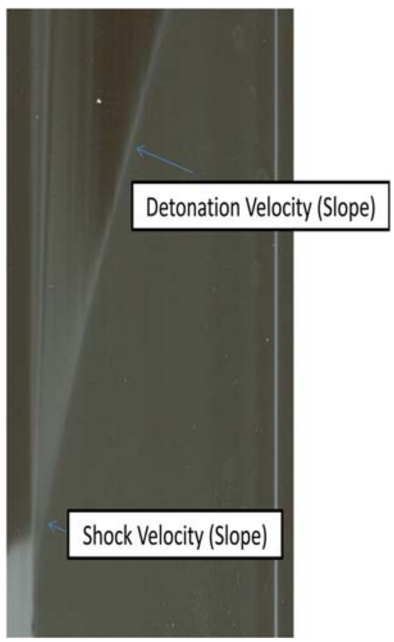

Figure 6. Streak image showing the transition to detonation

2D Corner Turning Test

2D corner turning test shall be conducted to fine tune the 2D characteristics of the reactive flow model. IM explosives usually have poor corner turning performance. A 2D corner turning test is performed to predict the corner turning behavior of an IM explosive in the reactive flow model. Detonation waves in non-ideal explosives have curved wave fronts. This curvature results from the reacting explosive having a finite size, a varying energy release rate and hydrodynamic flow. Detonation velocity and the wave front curvature data are used to calculate reaction zone length. An example setup for a corner turning test is shown in figure 7 where 3.75"D Pentolite boosters are used to initiate the IM explosive first cased in an Expanded Large Scale Gap Tube (ELSGT) and then an unconfined cylindrical billet of the IM explosive with piezo pins and the side of the unconfined billet will be streaked to obtain breakout results.

Figure 7. Example of 2D Corner Turning Test Setup

The ability of a detonation wave to turn a corner is a complicated function of wave shape, stress and initiation of the explosive. Corner turning experiments using flash x-ray have shown that substantial amount of material at corners go un-reacted. The understanding of how a detonation wave turns a corner is of great practical importance to insure proper performance of many explosive devices.

For ideal corner turning, the detonation wave turns the corner with radial detonation velocity approaching full detonation velocity. For non-ideal corner turning, the detonation wave turns the corner but the radial detonation velocity is slower. First breakout point is on the side or on the pole depending on the height of the charger Could see possible dead zones (Un-reacted HE). For poor corner turning, the detonation wave tunnels into HE and never breaks out the side. First breakout point is at the center of the cylinder on the top face. These different scenarios were modeled and the outputs are shown in figure 8.

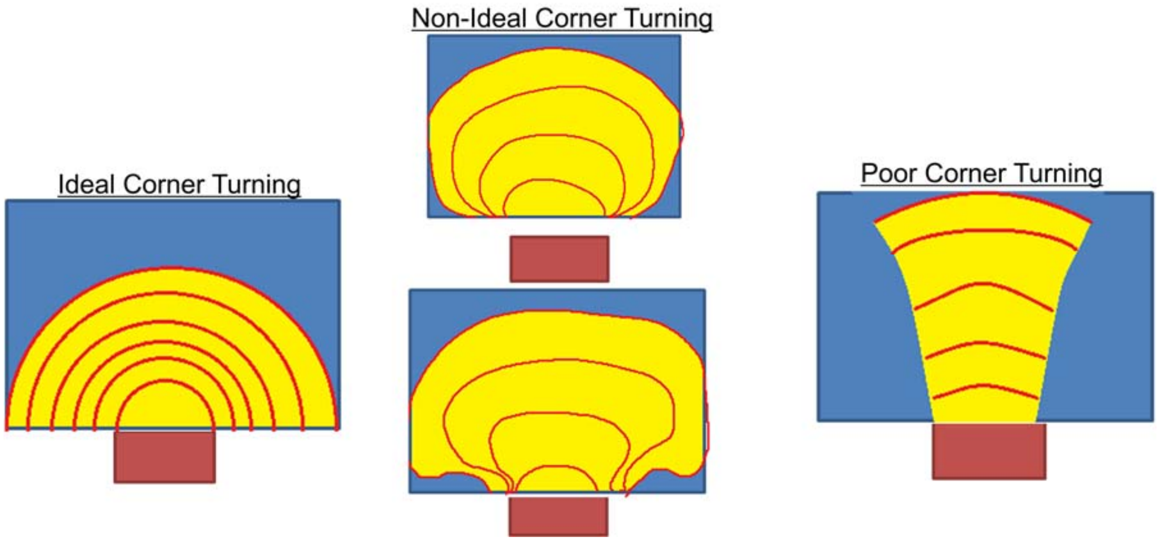

Figure 8. Modeling results for Corner Turning

Cutback Test

The cutback test in conjunction with the wedge test provides the data to determine the coefficient for the un-reacted equation of state and the reaction rate laws. The run to detonation data obtained from the wedge test shall be used to populate the test matrix for the cutback test. The cutback test will help determine how the pressure builds up during the run up (detonation ramp up) and will also give the properties of the un-reacted material. The data obtained from this test series will help parameterize the reaction rates for your explosive. Typically an embedded gauge gas gun test is conducted for the cutback test series but if resources are limited, then the cutback test can be conducted with PDV at the output end of the explosive (booster driven [Pentolite] cutback design) shall be used as an alternative as shown in figure 9. Cutback samples at various thicknesses are shown in figure 10.

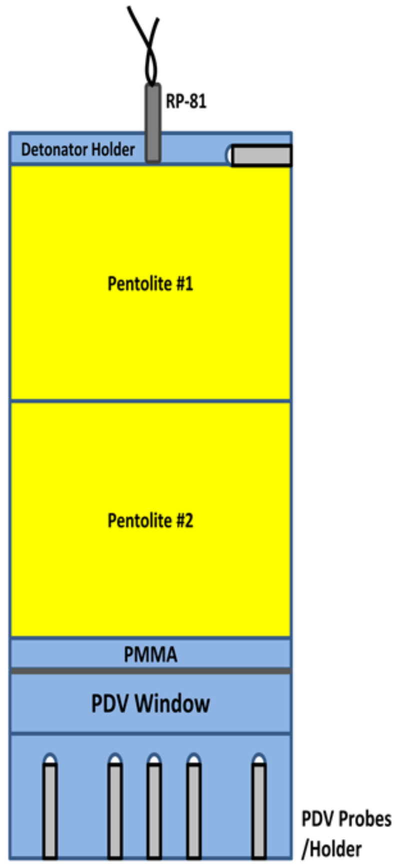

Figure 9. Cutback test setup

Figure 10. Example of cutback test samples

Cold Confined Detonation Velocity and CJ Pressure Testing

Cold temperatures have been shown to have an effect on the kinetics of IM explosives (TATB), especially initiating at near critical diameter, temperature could cause a change in the performance that would affect the likelihood of initiation. Earlier discussions showed the results of unconfined rate sticks to determine critical diameter and detonation velocity. This test series evaluated the performance at cold with confinement close to what the explosive would see in the end item it will be implemented into. This is a good screening tool and the results can be used to validate the reactive flow model. The test setup example shown in Figure 11 utilizes an ELSGT using piezo pins (along the side of the cylinder to obtain time of arrival (TOA), which can then be correlated to detonation velocity along the cylinder) and PDV to determine wave curvature.

The objective of this set of experiments is the following; characterize wave curvature and velocity of a cylinder loaded with an IM explosive. Of primary importance is the recording of the early time wall-velocity (0 to 80us) and the wave curvature as captured by PDV on the end-cap of the explosive charge as shown in figure 12. An eight-channel, Photonic Doppler Velocimetry (PDV) system should used to obtain wave curvature.

Figure 11. Example of Cold Confined Detonation Velocity and CJ Pressure Test

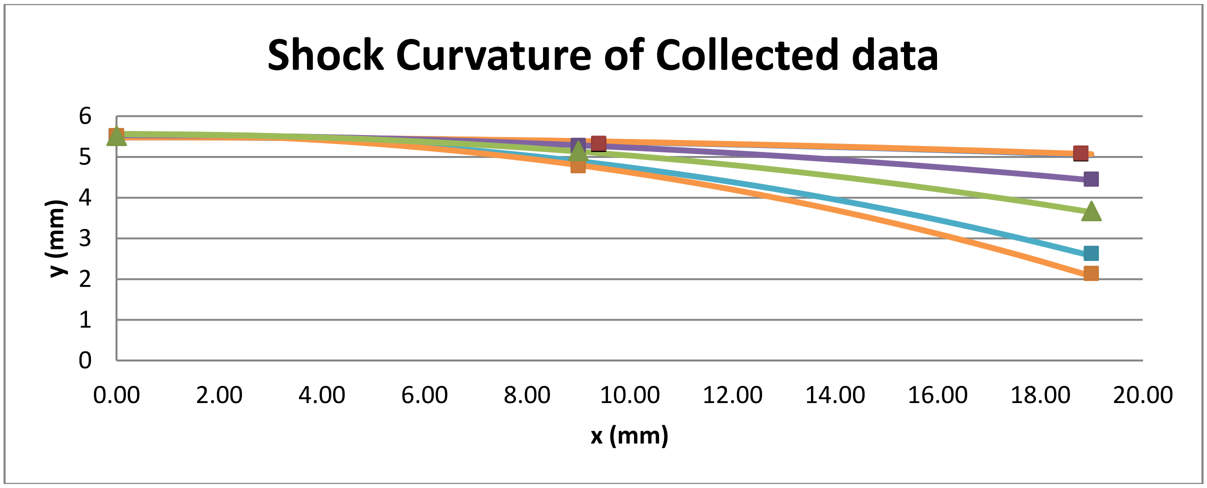

Figure 12. Example of post-test PDV wave curvature data

Conclusions

In order to develop a Hydrocode model, the following properties need to be obtained: reactive and non-reactive equations of state as well as properties of the reaction at the detonation front. Use data from the ignition studies to parameterize reactive flow model. Plug the reactive flow model into a Hydro code solver (CTH, ARES, CALE, ALE3D). Develop a Hydro code model for each test and compare results to experimental data Validate/tune reactive flow model until Hydro code models match experimental data. Use Hydro code solver to asses design iterations and optimize design. Sub-scale tests will need to be conducted in order to confirm performance of the new design. Conduct full-scale tests to confirm operational performance in updated system. The validated reactive flow model can then be applied to any munition application that wishes to utilize the specific insensitive explosive material.

References

1. AOP-7: Manual of Data Requirements and Tests for the Qualification of Explosive Materials for Military Use. Edition 2 Rev. 3. April 2008.
2. Gibbs, T. R. and Popolato, A., eds., LASL Explosive Property Data, University of California Press, Berkeley, CA, 1980, pp. 295-296.