LLNL-PROC-414031

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June 17, 2009

APS Shock Compression of Condensed Matter 2009
Nashville, TN, United States
June 28 – July 3, 2009

MODELING LX-17 DETONATION GROWTH AND DECAY USING THE IGNITION AND GROWTH MODEL

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Abstract. The previously established Ignition and Growth reactive flow model for the detonating triaminotrinitrobenzene (TATB) based plastic bonded explosive LX-17 is applied to recent experimental detonation propagation/failure experiments using unconfined, lucite confined, and copper confined cylinders. The model also simulates to corner turning experiments in which steel and lucite act as boundary materials. Finally, the model is used to calculate a one-inch diameter "Hockey Puck" test in which the booster explosive is HMX-based rather than TATB-based. Since the LX-17 Ignition and Growth model parameters are normalized to a great deal of one-, two- and three-dimensional detonation propagation data, they accurately predict all of this new experimental detonation velocity and arrival time data.

Keywords: Triaminotrinitrobenzene, Detonation failure, corner turning, Ignition and Growth
PACS: 82.33.Vx, 82.40.Fp

INTRODUCTION

The Ignition and Growth reactive flow model [1] must accurately simulate shock initiation and detonation wave propagation of triaminotrinitrobenzene (TATB) based plastic bonded explosives (PBXs) in all possible geometries. A great deal of 1D, 2D and 3D experimental data has been used to parameterize detonation models for LX-17 (92.5% TATB plus 7.5% KelF binder) and PBX 9502 (95% TATB plus 5% KelF binder) [2-8]. Recently several new sets of experimental LX-17 detonation data were published by Souers et al. [9]. Unconfined, lucite confined and copper confined LX-17 cylinders of various diameters were fired to better determine the detonation versus failure properties of LX-17. Corner turning experiments in which LX-14 (95% HMX, 5% Estane by weight) overdrove LX-17 detonation waves around 90˚ corners containing steel or lucite. Finally, a one-inch radius LX-17 "Hockey Puck" experiment was fired using an LX-07 (90% HMX, 10% Viton by weight) booster explosive rather than the usual Ultrafine TATB booster. The resulting experimentally measured detonation velocities and arrival times are compared to the Ignition and Growth LX-17 detonation model predictions.

IGNITION AND GROWTH MODELING

The Ignition and Growth reactive flow model [1] uses two Jones-Wilkins-Lee (JWL) equations of state in the form:

$$p = Ae^{-R1V} + Be^{-R2V} + \omega C_vT/V \qquad (1)$$

where p is pressure in Megabars, V is relative volume, T is temperature, ω is the Gruneisen coefficient, C_V is the average heat capacity, and A, B, R_1 and R_2 are constants. The reaction rate equation is:

$$dF/dt = \underbrace{I(1-F)^b(\rho/\rho_0 - 1 - a)^x}_{0<F<F_{Ig\max}} + \underbrace{G_1(1-F)^c F^d p^y}_{0<F<F_{G1\max}} + \underbrace{G_2(1-F)^e F^g p^z}_{F_{G2\min}<F<1} \quad (2)$$

where F is fraction reacted, t is time in µs, ρ is the current density, ρ_0 is the initial density, p is pressure in Mbar, and I, G_1, G_2, a, b, c, d, e, g, x, y, and z are constants. The LX-17 parameters used here are the same as listed by Tarver [4].

LX-17 CYLINDER TEST RESULTS

The unconfined failure diameter of an LX-17 cylinder is estimated to be approximately 11 mm, while the copper confined failure diameter is about 8 mm [2]. With Lucite confinement, the LX-17 failure diameter must be between 8 and 12 mm. To check on these detonation propagation limits, seven LX-17 cylinder tests were fired and calculated using the LX-17 Ignition and Growth model parameters. A copper cylinder with an inner radius of 3.98 mm and an outer radius of 6.35 mm was filled with LX-17 and detonated. The resulting LX-17 detonation wave propagated steadily through the entire 255 long cylinder at an average measured detonation velocity of 7.34 mm/µs. An Ignition and Growth calculation of this test also detonated steadily along the entire length at an average detonation velocity of 7.38 mm/µs. A second copper cylinder with an inner radius of 3.175 mm and an outer radius of 6.355 mm was also fired. This cylinder failed to detonate in less than its 152 mm total length. Two longer copper cylinders with inner radii of 3.195 mm and outer radii of 6.345 also failed to detonate. An Ignition and Growth calculation of this test also failed to detonate in less than 10 cm of LX-17. The copper confined failure diameter is greater than 6.4 mm and less than 8 mm, and the LX-17 Ignition and Growth model predicts these limiting values well.

Two Lucite confined LX-17 cylinders were also fired. One had an inner radius of 6.4 mm and an outer radius of 7.9 mm. This test produced a steady detonation wave with an average velocity of 7.48 mm/µs. The corresponding calculation also detonated with an average velocity of 7.44 mm/µs. A second Lucite cylinder with an inner radius of 5.1 mm and an outer radius of 6.32 mm failed to detonate over its entire 152 mm length. The calculation of this test also failed to detonate. So the Lucite confined failure diameter is greater than 10.2 and less than 12.8 mm, and the model agrees with these experimental results.

One unconfined LX-17 cylinder with a radius or 5.56 mm was fired and failed to detonate. The calculation of this experiment also failed to detonate. Thus the Ignition and Growth predictions matched these cylinder test results for different degrees of confinement.

CORNER TURNING TEST RESULTS

Two sets of corner turning tests were fired in which 63.5 mm long by 6.35 mm radius LX-14 cylinders were detonated into unconfined 25.4 mm radius, 50.8 mm long LX-17 charges. A 6.35 mm thick plate of either steel or Lucite covered the remaining 19.05 mm of the rear of the LX-17 cylinder. A "dead zone" formed as the LX-17 detonation wave attempted to turn the corner. Time of arrival pins measured the position of the LX-17 detonation wave at several points along the charge axis and at four points along the steel or Lucite surface with the LX-17. The experiments measured longer transit times along the Lucite plates than along the steel plates and longer arrival times at the LX-17 outer boundaries.

The corresponding calculations produced similar results. The measured transit time across the four pins spaced from 12.7 to 24.61 mm for the one Lucite experiment where the first and last pins recorded was 3.36 µs, while the calculated transit time was 3.37 µs. The two steel experiments measured transit times of 2.22

and 2.69 μs, while the corresponding calculated transient time along the steel plate was 2.10 μs.

Figure 1 shows two sets of experimental and one set of calculated arrival times for steel and Lucite back plates. The arrival times were aligned based on the calculated times of 13.5 μs between the initiation of the LX-14 charge and the LX-17 detonation arriving at the 40 mm pin on its outer boundary. The experimental Lucite arrival times along the outer LX-17 boundary are given by solid lines and the calculated times by inverted triangles. The experimental steel arrival times are shown as dashed lines, while the calculated times as triangles. Good overall agreement was obtained between the experiments and the calculations for the distances at which the LX-17 detonation waves first reach the outer boundary. The steel back plates allow the LX-17 detonation waves to turn the 90° corners more effectively than do the Lucite plates, resulting in smaller "dead zones" of unreacted LX-17 and shorter arrival times at the outer edges of the LX-17 cylinders. No modeling results were reported by Souers et al. [9].

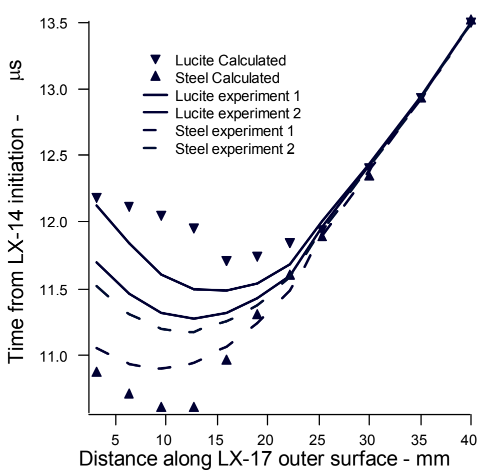

FIGURE 1. Experimental and calculated arrival times at the outer LX-17 boundaries for the Lucite and steel backed corner turning tests

LX-07 BOOSTER HOCKEY PUCK TEST

A one-inch radius LX-17 "Hockey Puck" experiment [4] was conducted using an LX-07 booster rather than the usual Ultrafine TATB booster. LX-07 has a higher chemical energy density and a smaller reaction zone than Ultrafine TATB. Thus it should initiate the initial diverging detonation wave in LX-17 more efficiently than does Ultrafine TATB. The subsequent corner turning of the LX-17 detonation wave may actually take slightly longer using LX-07, because the diverging LX-17 detonation wave has propagated farther and has to travel a longer distance back to consume the unreacted LX-17 in the "dead zone" region. Figure 2 shows that this is the case by comparing some of the experimental LX-07 breakout times with the average of three Ultrafine TATB tests. However, the difference is not much larger than the uncertainty in the three Ultrafine TATB booster shots. Also shown in Fig. 2 are Taranula model calculations reported by Souers et al. [9], which are not at all accurate in the corner turning region.

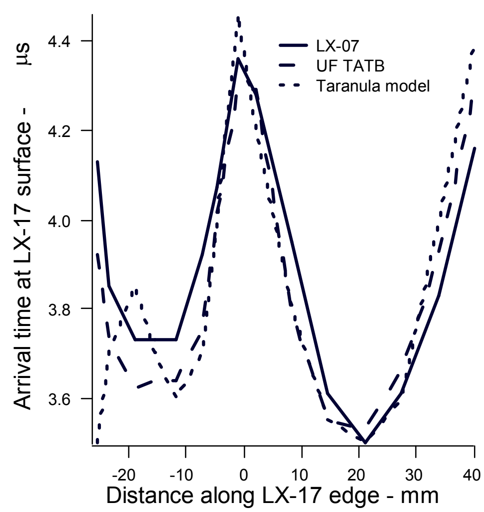

FIGURE 2. Arrival times at LX-17 edges for LX-07 versus Ultrafine TATB boosters in one inch radius Hockey Puck experiments

An Ignition and Growth calculation using an LX-07 booster shows the correct trends in arrival times. Since LX-07 ignites promptly and has a small reaction zone, there was no difference in assuming that LX-07 propagated as an ideal Chapman-Jouguet (C-J) or as an Ignition and Growth detonation reaction zone. Figure 3 shows the calculated arrival times using an LX-07 booster and an Ultrafine TATB booster. The LX-07 booster calculation predicts slightly smaller arrival times for the diverging section of the LX-17 detonation wave and slightly longer arrival times for the corner turning regionte. Also shown in Fig. 3 is the experimental data for one Ultrafine TATB test.

SUMMARY

The LX-17 Ignition and Growth detonation wave model accurately predicted the results of three recently published sets of experiments.

ACKNOWLEDGEMENTS

This work was performed under the auspices of the United States Department of Energy by the Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

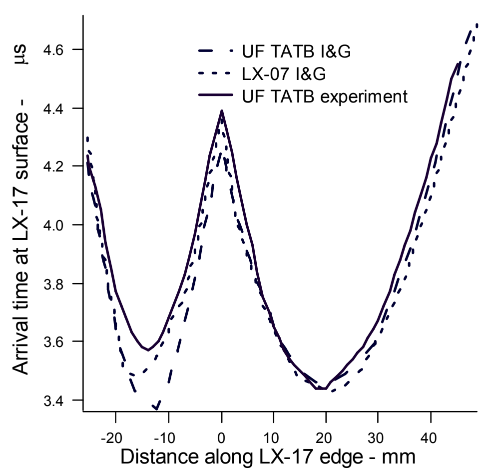

FIGURE 3. Experimental versus calculated Hockey Puck arrival times for one inch radius LX-17 charges

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