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Development of a Detonation Profile Test for Studying Aging Effects in LX-17

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Abstract

A new small-scale Detonation Profile Test (DPT) is being developed to investigate aging effects on the detonation behavior of insensitive high explosives. The experiment involves initiating a small LX-17 cylindrical charge (12.7 - 19.1 mm diameter x 25.4 - 33 mm long) and measuring the velocity and curvature of the emerging detonation wave using a streak camera. Results for 12.7 mm diameter unconfined LX-17 charges show detonation velocity in the range between 6.79 and 7.06 km/s for parts up to 33 mm long. Since LX-17 can not sustain detonation at less than 7.3 km/s, these waves were definitely failing. Experiments with confined 12.7 mm diameter and unconfined 19.1 mm diameter samples showed wave velocities in the range of 7.4 - 7.6 km/s, values approaching steady state conditions at infinite diameter. Experiments with unconfined 19.1 mm diameter specimens are expected to provide reproducible and useful range of detonation parameters suitable for studying aging effects.

Introduction

The ability of a detonation wave to diverge so that it travels at a right angle to the direction of initiation is needed to complete the detonation of the entire charge of insensitive high explosive (IHE) materials such as LX-17 (92.5 wt% TATB, 7.5 wt% Kel-F). The divergence or 'corner-turning' testing, measuring the breakout distance from the initiation plane as the detonation wave emerges from the side of a cylindrical charge, has been done at Pantex for production qualification and in enhanced surveillance studies (1). The breakout distances show small changes with age at approximately the same density, suggesting that the wave divergence in IHE changes slightly in aged or thermally damaged materials.

This assessment on possible aging effects is not satisfactory because the data are limited. Additional divergence data on aged and damaged materials are required. Divergence testing is limited by the large sample required (145g) and material availability. In addition, simulated aged samples are not large enough for divergence tests. Therefore, a new test is needed to facilitate characterizing smaller samples and a larger variety of stockpile returned and simulated aged parts.

The new Detonation Profile Test (DPT) was designed to provide a steady state wave breakout from as small a sample as possible. Such an approach requires characterization of samples above LX-17 failure diameter. The exact failure diameter of LX-17 has not previously been measured. Campbell and Engelke (2) and Campbell (3) have studied the failure diameter in TATB-containing formulations under various temperatures. Interpolation of their results for 90% and 95% TATB formulations suggests an estimated critical diameter for LX-17 of around 12 mm.

Our initial experiments began with samples at 12.7 mm diameter. The effects of diameter, sample length, density and confinement were investigated to identify the parameter spaces that are sensitive for studying the changes in LX-17 detonation velocity and detonation wave breakout curvature.

The new test is also amenable to modeling. The detonation velocity and breakout profile have been successfully calculated with the Ignition and Growth model (4). Data on a variety of aged samples will provide validation data for developing models to predict effects of aging on IHE divergence.

This smaller Detonation Profile Test (an order of magnitude smaller in specimen mass than that required in Pantex Divergence test) will leverage a wealth of characterization information that has been obtained on these specimens in core surveillance and enhanced surveillance activities. The test is also easily extended to study other IHE materials such as PBX-9502 and UF-TATB because both of these materials have failure diameter smaller than that of LX-17.

EXPERIMENTAL

A schematic of the Detonation Profile test and a picture of an unconfined test assembly are shown in Figure 1. The test involves initiating a cylindrical (e.g. 12.7 mm diameter x 25.4 mm long, 6.1g) LX-17 test specimen using a PBX-9407 booster (12.7 mm diameter x 12.7 mm long). The booster is initiated by a RP-2 detonator. The opposite surface, where the detonation wave emerges, has a squared groove 2 mm wide x 1mm deep. This surface is illuminated with 532 nm laser light. A streak camera, looking perpendicular to the notched surface, records the extinction of the laser light as the wave breaks out on the surface. This technique provides us with a high-resolution spatial and temporal profile of the emerging detonation wave as well as the timing between the bottom and top surfaces of the groove. The travel time is used to determine the wave velocity.

Initial samples were die-pressed to final dimensions at 200 MPa and 105°C. Most specimens were machined from larger samples obtained from hydrostatically pressed hemispheres. Specimens with lower densities were prepared by thermally cycling them between –50°C and 70°C until the desired density is reached. Specimen density was measured by an immersion density technique. The groove was machined precisely in one of the surfaces of the cylindrical specimen. The groove depth was measured using a contact depth gauge. All measurements were done after thermal cycling.

RESULTS AND DISCUSSION

Initial experiments investigated the effects of booster size, sample diameter, sample length and confinement. Once the optimum design parameters for producing a reproducible and a steady-state detonation wave are found, subsequent experiments will be conducted to study effects of density and temperature for baselining.

Effects of PBX-9407 booster size - The initiation chain for this test was kept as similar to that of the standard Pantex Divergence test as possible. The same booster material (PBX-9407) and diameter (12.7 mm) were used. The PBX-9407 pellet at 1.63 g/cc provides a shock pressure about 270 kbar, close to the C-J pressure of LX-17. The output of the PBX-9407 booster pellet was characterized in a series of experiments. The profiles of pellets with thickness from 3 mm to 19 mm showed increasing flatness with increasing thickness. Many tests with 6 mm thick booster pellets failed to initiate LX-17, resulting in yellowish residues. All booster pellets with thickness of 12 mm successfully initiated the LX-17 pellets. As the results of these experiments, a standard booster size of 12.7 mm diameter x 12.7 mm long was selected in subsequent experiments.

Effects of sample length - Initial tests at 12.7 mm diameter with lengths up to 33 mm were completed. The wave profiles and measured velocities are shown in Figure 2. In these experiments, the PBX 9407 booster was composed of two 6 mm-thick (also at 12.7 mm diameter) pellets. The detonation velocities appear to decrease slightly from 7.2 km/s at 12.7 mm to 7.02 km/s at 33 mm. It appears that the detonation wave is failing. Therefore, we are at or below the failure diameter. Some of these experiments were repeated with a slightly longer booster (12.7 mm) and the measured velocities increased to about 7.35 km/s. The limited data and the relatively high standard error in the velocity measurements (about 1.5%) makes analysis of the data difficult. However, it is clear that detonation conditions near LX-17 failure diameter are highly sensitive to initiation input pressure profile and the sample length. Specimens longer than 33 mm are not desirable because of the availability of stockpile returned parts. We have been investigating other variables such as confinement and diameter in order to keep the specimen length as short as possible.

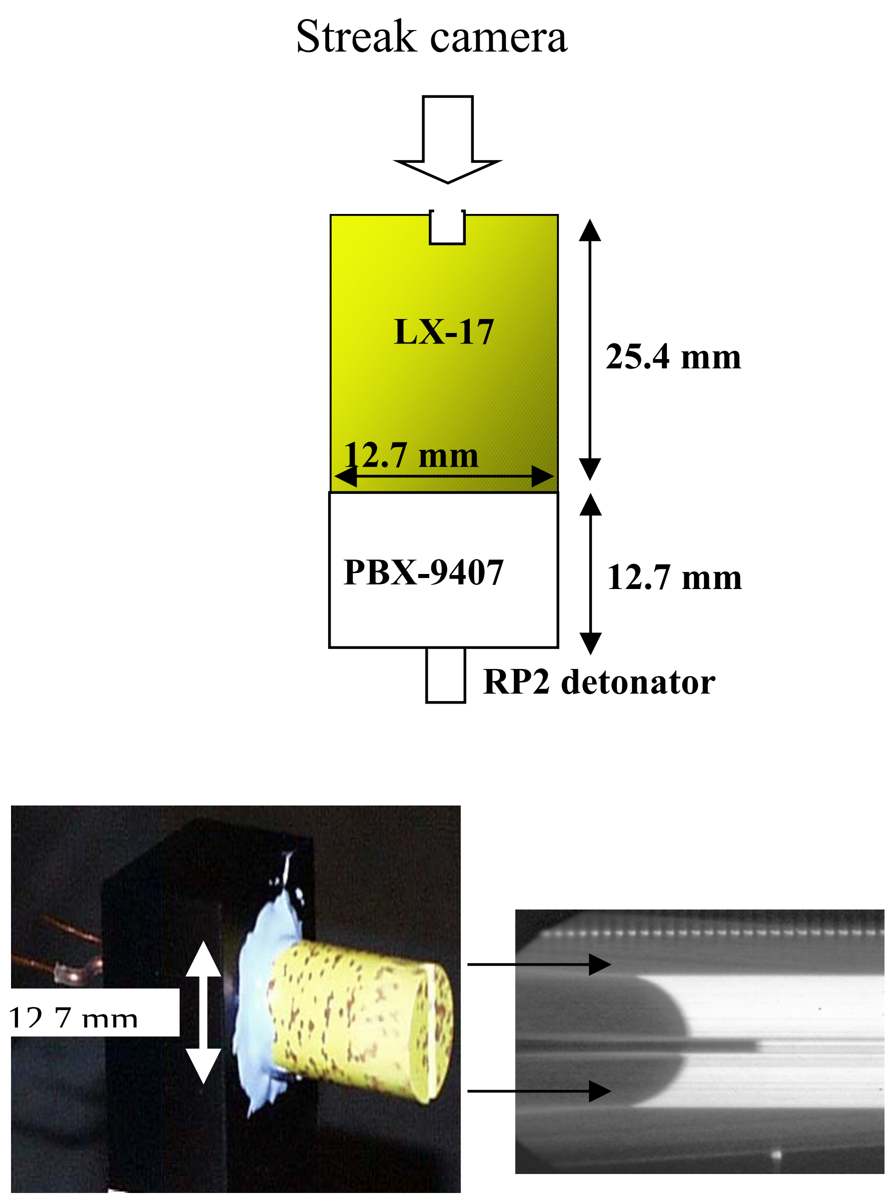

Figure 1. Schematic of the Detonation Profile test design, a picture of an unconfined test

assembly and the resulting streak camera record

The breakout profiles of the emerging shock waves are also included in Figure 2 together with an input wave from the PBX 9407 booster. The wave centers are superimposed for comparison purpose. While there appears to be flatter profile with increasing sample length, the comparison is complicated by the asymmetry in the breakout profiles. The improved initiation chain alignment and higher resolution digitizing process are expected to provide more symmetric and smoother profiles for comparison.

Effects of bulk density - Density is the primary factor influencing the detonation wave divergence and velocity. Several tests at 3 different densities, 1.915, 1.910 and 1.890 g/cc, were run to explore the test sensitivity to density. Lower density specimens were prepared by thermal cycling between - 50°C and 70°C to induce ratchet growth until the desired density is reached. Further details of this procedure is provided elsewhere (5). The measured detonation velocities for these 3 densities in unconfined tests at 12.7 mm diameter x 25.4 mm long are shown in Figure 3. The

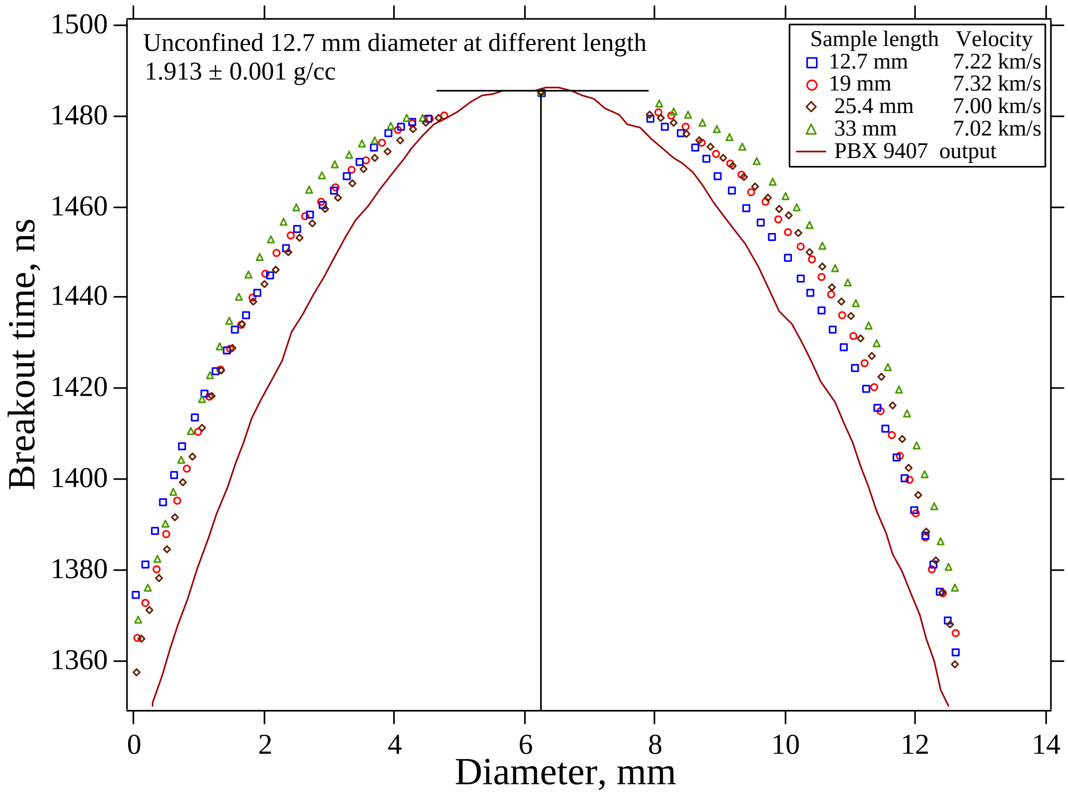

Figure 2. Effect of length at 12.7 mm diameter on detonation wave velocity and curvature. PBX 9407 booster is 12 mm long (from two consecutive 6 mm long pellets).

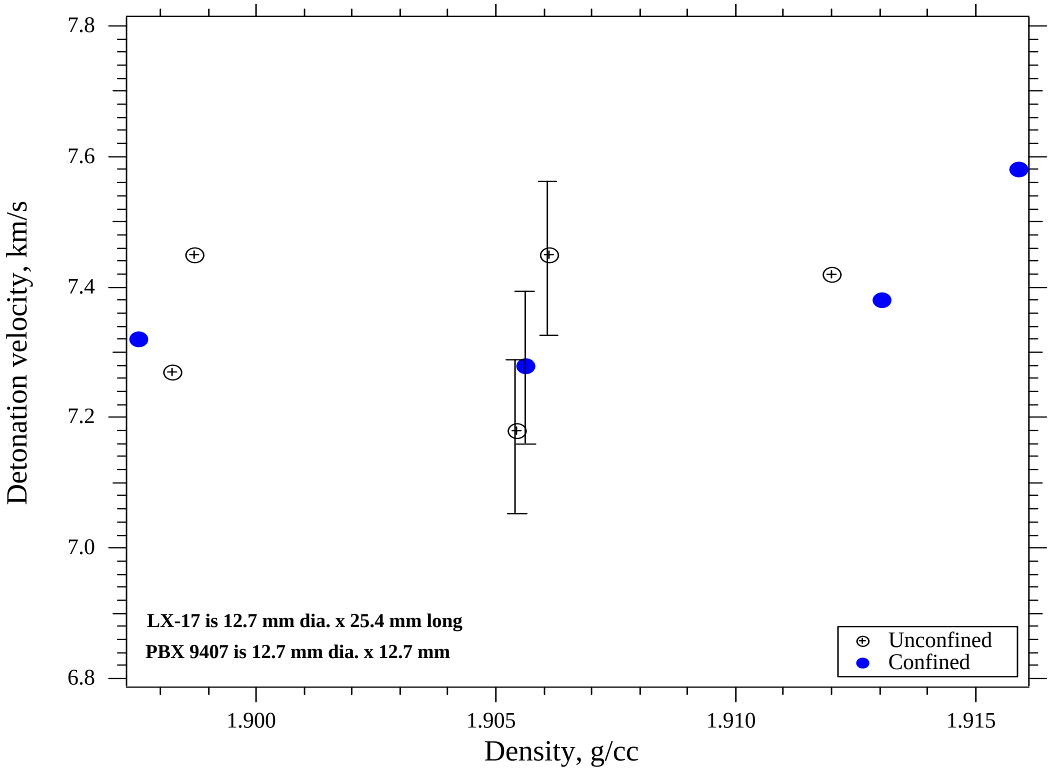

Figure 3. Effects of density on detonation velocity for unconfined and confined 12.7 mm dia. Confined charges use 6.4 mm thick Teflon sleeve (see text).

velocities are around 7.4 km/s and do not show the expected dependence on density. We attribute this to the unsteady detonation conditions near the failure diameter. In addition, the relatively large experimental error of about 1.5% complicated the data analysis. Improvements are being made to reduce the standard error. We expect that confinement and larger diameter will provide more favorable conditions leading to steady state detonation behavior.

Effects of confinement - The effect of confinement on 12.7 mm diameter samples is included in Figure 3. The confinement was established using 6.4 mm thick concentric Teflon tube. The measured velocities for 25.4 mm long samples are approximately 7.4 km/s as well with the exception of one test at the highest density. Additional data are needed to clearly elucidate the effect of confinement at this diameter.

Effects of charge diameter - Recent experiments measured detonation velocities at 15.9 and 19.1 mm diameters. Results from two sets of data using two different booster sizes are shown in Figure 4. The booster design apparently affected the wave velocities. Experiments with a 12 mm long booster (two 6 mm pellets) gave significantly lower wave velocities. Tests with a single 12.7 mm booster showed slightly higher velocities (than those with 2 x 6 mm booster) and comparable detonation velocities in different LX-17 diameters and length. These values, however, are still below reported steady state values at 7.63 km/s (at infinite diameter.).

The test design with unconfined samples at 19.1 mm diameter and 33 mm long (with a single 19.1 mm diameter x 12.7 long mm booster) is selected for further study. Such a sample represents an eight-fold reduction in size from the standard Pantex Divergence specimen and appears sufficiently large to support a reproducible and steady-state detonation wave.

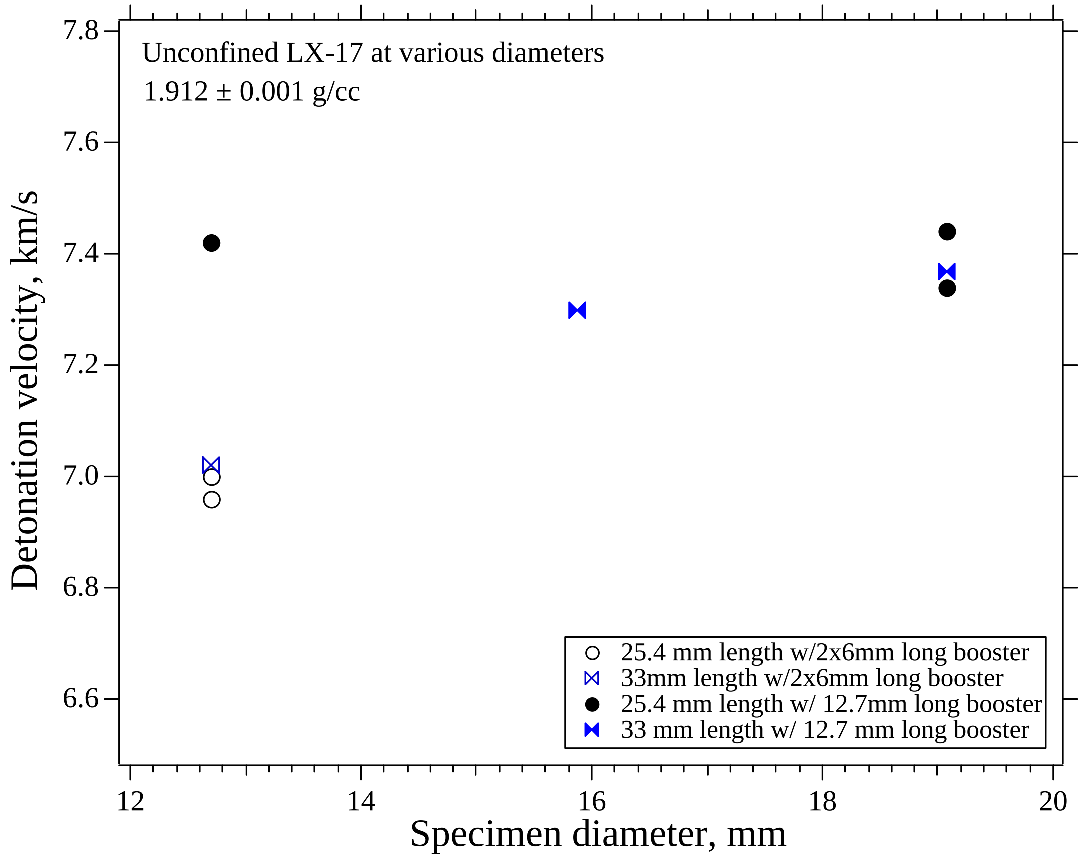

Figure 4. Effects of diameter on detonation wave velocity at 2 different sample lengths

Ratchet growth to achieve homogenous bulk density reduction - The preparation of specimen with a range of density is important so that accurate measurements on the wave breakout parameters can be obtained for performance baselining. Initial pressing exercises using uniaxial die press did not produce homogeneous samples as suggested from the external appearance of the part (5). Furthermore, parts with large aspect ratio (length/diameter larger than one) are not expected to have a uniform density distribution based on prior pressing experience.

Ratchet growth in LX-17 due to thermal cycling was used to induce irreversible growth on isostatically pressed parts (4). These samples were thermally cycled between - 55°C and 70°C and their bulk sample densities were reduced by as much as 2% over 40 thermal cycles (5). Several samples with lower densities were successfully obtained based on the relationship established here.

CONCLUSIONS

A new small-scale Detonation Profile Test is being developed to characterize the detonation velocity and wave curvature of new and aged LX-17 materials. Experiments showed that the measured detonation wave velocity and curvature is highly dependent on booster length, confinement, sample diameter and length. Detonation behavior at unconfined 12.7 mm diameter yields velocities well below expected steady state value and little detectable sensitivity to density. The results are attributable to behavior near LX-17 failure diameter. Confinement with 6.4 mm thick Teflon sleeve produced larger velocities and broader wave breakouts. Selected experiments with unconfined 19.1 mm diameter showed higher velocities and more reproducible results than those with unconfined 12.7 mm diameter. The error in the velocity measurement was determined at 1.5%, which complicated data analysis. This experimental error and wave breakout symmetry are expected to improve with better experimental techniques. The results at 19.1 mm diameter appear promising. Further testing at this size will be conducted.

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