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Gap Test Calculations and Correlations

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NEWGATES (New Excel Worksheets on GAp TESts)is a large data base and computational tool for gap test data. NEWGATES includes pressure calibration curves for the various gap tests based on test results, numerical simulations and analytical calculations. NEWGATES can also calculate the shock pressure transmitted in the tested energetic using the attenuator material Hugoniot and tested energetic unreacted Hugoniot. We have conducted studies investigating laboratory test characteristics correlations. Correlations found included: NOL-SSGT to NOL-LSGT, NOL-LSGT to critical diameter, critical diameter to Held criteria and NOL-LSGT to density for a given explosive. The Gurney energy, the Figure of Insensitiveness of the Rotter Impact test, the detonation velocity and the detonation pressure characteristics do not provide any correlation relationship with the gap test results or critical diameter. Most recently, NEWGATES has been modified to include an improved NOL small scale to large scale gap test correlation and a critical diameter estimation calculation.

INTRODUCTION

The Munitions Safety Information and Analysis Center (MSIAC) has developed a number of safety related computational tools, including NEWGATES (New Excel Worksheets on GAp TESts) [1] which is a large data base and computational tool for gap test data. NEWGATES currently contains information about 10 gap tests (dimensions, scope, principles); pressure calibration curves; time calibration curves; shock curvature calibration curves; 1455 gap test results; and over 250 Hugoniots. In order to reduce the cost, time and risks involved in the conception of an explosive researchers have often tried to determine ways to predict the sensitivity properties of an explosive. We have conducted studies investigating laboratory test characteristics correlations [2], including the NEWGATES gap test data. The explosive characteristics investigated included the Held criterion, the weight percentage of RDX, the composition density, the composition, the Gurney energy, the Rotter impact test and the detonation state properties.

ATTENUATOR AND ACCEPTOR GAP TEST PRESSURES

Reported gap test “incident pressures” represent the shock pressure in the attenuator material just before it shocks the energetic material being tested. As the shock pressure is reduced as it passes through the attenuator, a pressure calibration curve is required [3,4]. Figure 1 presents a general diagram of a gap test and calibration curves for the Naval Ordnance Laboratory – Large Scale Gap Test (NOL-LSGT). Donor-produced shock pressures are sustained at higher levels for longer distances as either the test diameter or confinement is increased. This makes the calibration curve highly test dependent. NEWGATES includes pressure calibration curves for the various gap tests based on test results, numerical simulations and analytical calculations.

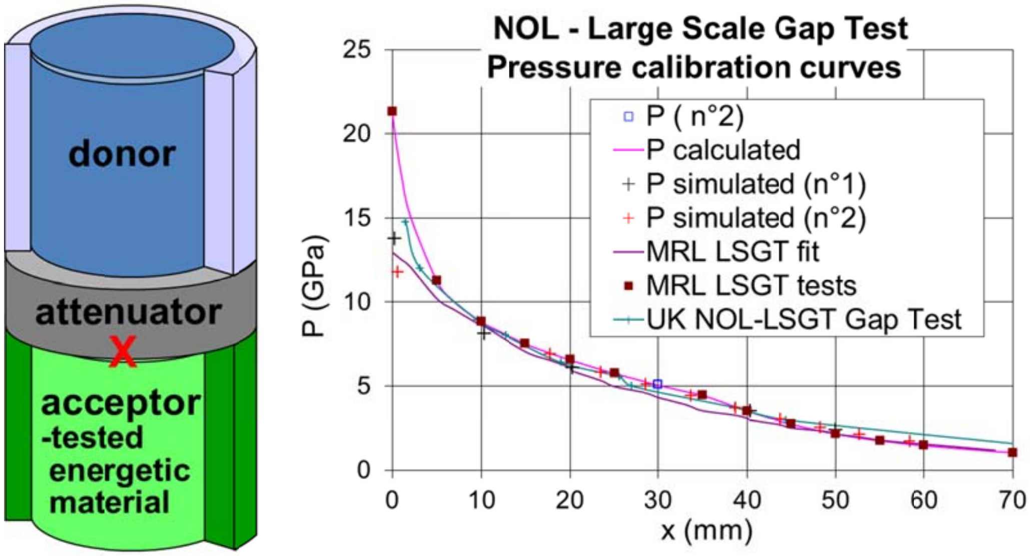

Figure 1. Gap test diagram (left) and calibration curves for the NOL-LSGT.

NEWGATES can also calculate the shock pressure transmitted in the tested acceptor energetic using the attenuator material Hugoniot and tested energetic unreacted Hugoniot. The acceptor shock pressure pressure can be either higher or lower than the attenuator shock pressure, depending on the unreacted Hugoniot of the acceptor energetic. Figure 2 presents a diagram of the acceptor shock pressure calculation.

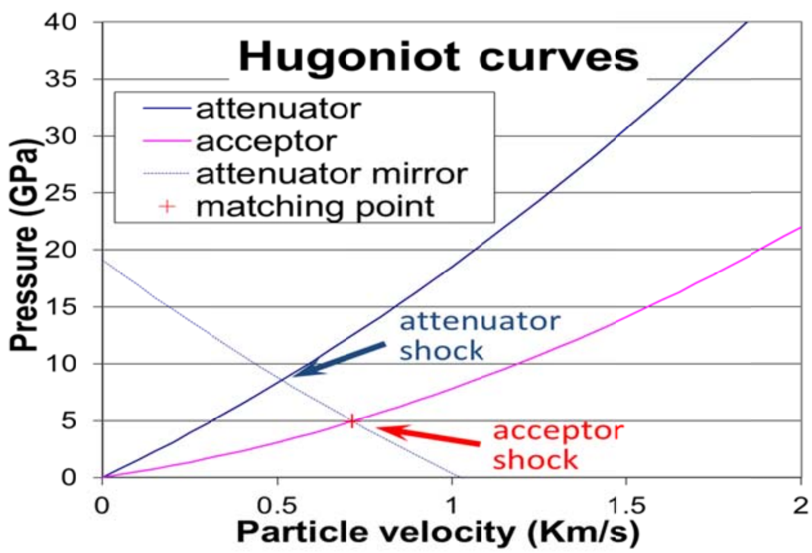

Figure 2. Calculation of acceptor shock pressure from Hugoniot characteristics.

As the unreacted Hugoniot of most tested energetics is not available, NEWGATES includes an analytical module that estimates the unreacted Hugoniot of a material using a rule of mixtures approximation [5,6]. The unreacted Hugoniot approximation requires the material density, the composition and the Hugoniots of its ingredients. The unreacted Hugoniot calculation includes porosity effects of a mixture at less than the theoretical maximum density [7]. The required input data are the mass percentages of the different ingredients, the density of the composition and the pressure range for the Hugoniot calculation. Up to 5 ingredients can be used to calculate the Hugoniot mixture. Figure 3 presents a comparison between the calculated mixed Hugoniot, a standard Hugoniot fit using experimental data and the associated experimental data for Rowanex 1400 [8].

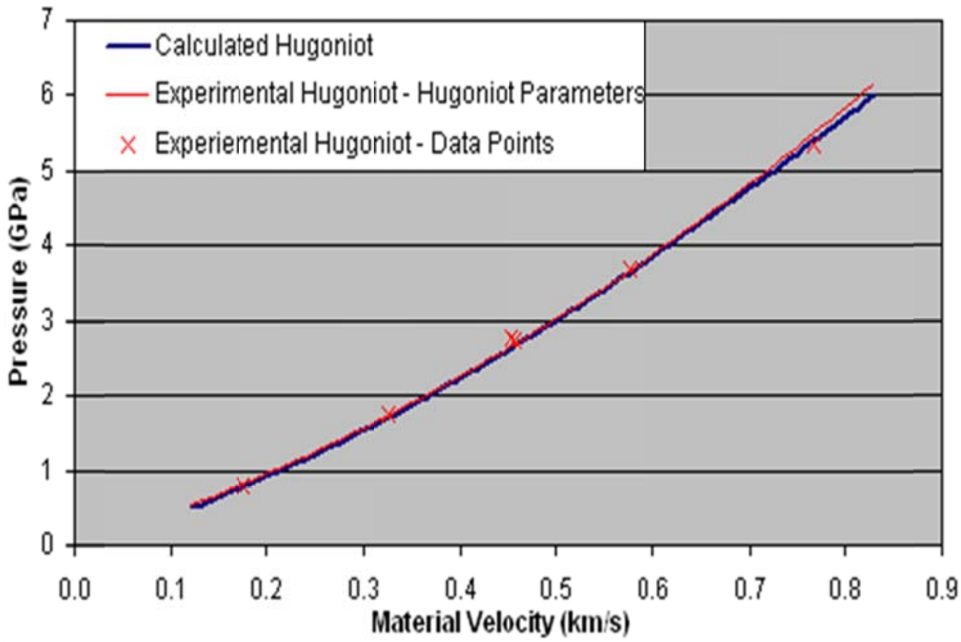

Figure 3. Comparison between the calculated mixed Hugoniot, a standard Hugoniot fit using experimental data and the associated experimental data for Rowanex 1400.

NOL LARGE VERSUS SMALL SCALE GAP TESTS

Gap tests of different sizes and geometries give different results in term of gap length for the same material. Additionally, the use energetic materials with large critical diameters compared to the diameter of a given gap tests can yield misleading results. It is therefore suggested that correlations for different gap tests are only appropriate for materials with critical diameters on the order or smaller than the diameters of the gap tests being correlated. The main point of this interrogation was therefore to add more data to an existing correlation of interest made by Donna Price [9] in 1966. The two tests of interest are the NOL-LSGT and the NOL small scale gap test (NOL-SSGT). As the two tests came from the same laboratory, the methods and protocols used are similar for these two tests. The incident initiation pressures were compared for nine different explosives at several densities. She made the correlation with twenty-nine values. In this investigation, eight values (for six new explosives) were added at this comparison and several larger critical diameter explosives were removed. Figure 4 shows the comparison between the two gap tests. The resulting correlation does not change significantly the comparison. This new correlation was implemented into NEWGATES. It is interesting to note that although a correlation exists, it is not particularly strong.

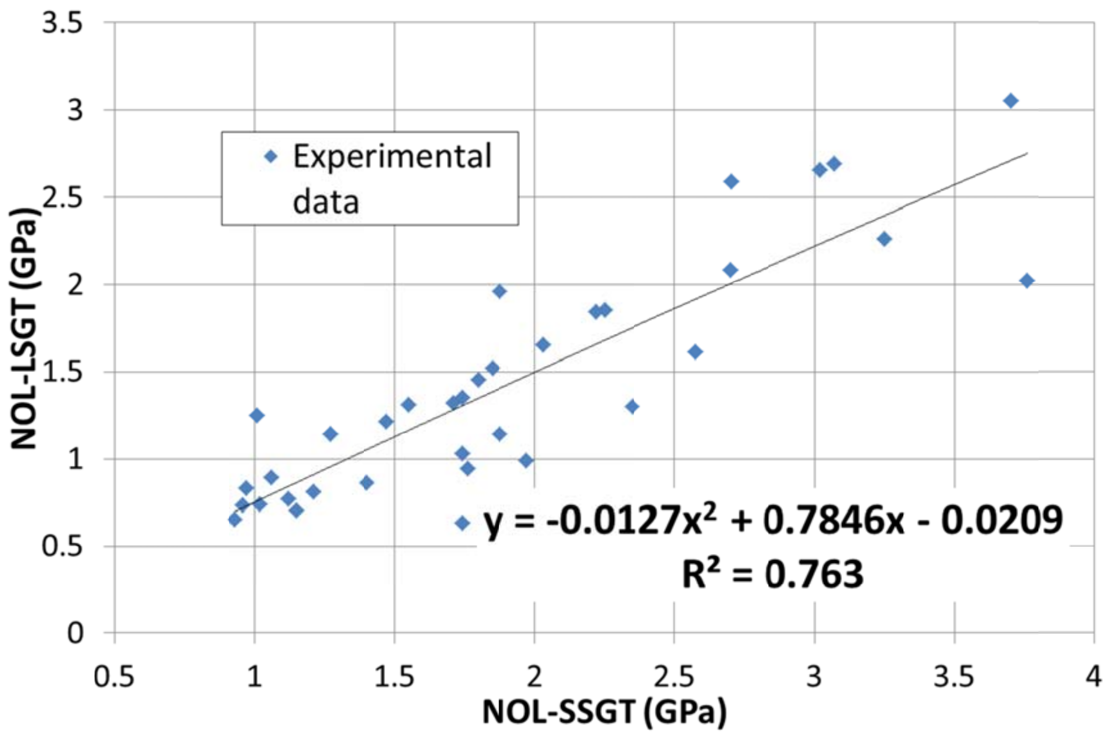

Figure 4. Comparison and correlation between NOL small scale and large scale gap test results.

CRITICAL DIAMETER VERSUS GAP LENGTH

Patel [10] previously looked for critical diameter correlations. In particular, he noted a correlation between critical diameter and Held's criteria for shaped charge jet initiation. He did not investigate gap test correlations. To expand upon Patel's work, this work used the critical diameter data held within EMC [11] and compared this to the gap data held in NEWGATES for the same formulations. The first gap test chosen was the NOL-LSGT gap test. The comparison has been made for forty-three different energetic materials. The results of critical diameter tests are dependent upon the exact composition, the density, the particle size, the ingredients properties and the composition processing. It is common to see a range of values for the same explosive in the same conditions. In this case, and if the values are similar, an average has been made. If the database indicated a range of value like "between 30 and 40 mm", the average of the two values has been made. And finally if the critical diameter was indicated below a certain value such as "< 3 mm", this value was selected if it was below 10 mm. Above 10 mm (e.g. "<70 mm"), the explosive has been removed. The results of this correlation are shown in Figure 5. A graph of the gap length and the gap pressure versus the critical diameter under logarithmic regression was interesting, providing a correlation coefficient R-squared of 0.7982. Although this would mean that it has been found empirically that there is a correlation, the correlation is not particularly strong and should not be construed to be a fundamental physically based relationship. There is significant experimental evidence showing that small critical diameters can be realized for less shock sensitive energetic materials. The identification of such materials is both an ongoing research area for ultra-fine grain scale explosives [12] and has also been observed for some higher performance reduced sensitivity rocket propellants [13].

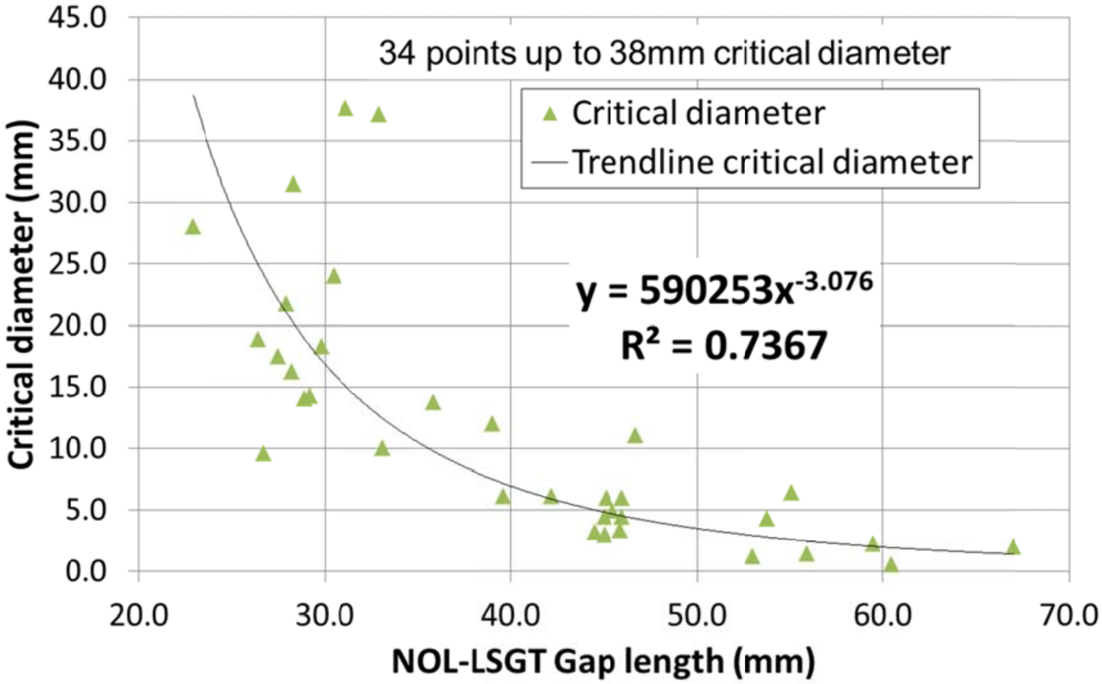

Figure 5. Critical diameter correlation to LSGT gap length.

HELD CRITERION VERSUS CRITICAL DIAMETER

The Held criterion [14] is a measure of an energetic material's susceptibility to initiation from a copper shaped charge jet. Some studies indicated that when dealing with initiation due to shaped charges, the square of the velocity of the minimum jet needed to cause initiation multiplied by its diameter is nearly constant for an energetic material. This constant is called the Held criterion, and is treated as a constant unless the jet material is changed [15, 16]. Patel [10] previously noted a correlation between critical diameter and Held's criteria for shaped charge jet initiation. The relation found by Patel has the attribute that if the critical diameter is less than 4.05 mm, the Held criterion becomes negative. This was due to using only data for explosives with critical diameters down to 4mm. Additionally, the largest critical diameter used was 9mm. Therefore, a new correlation was investigated using a broader data set down to a 2.5mm critical diameter and up to a 13mm critical diameter [16, 17, 18]. After comparing various correlation mathematical forms, a power correlation was chosen. Figure 6 presents the correlation and a comparison to data.

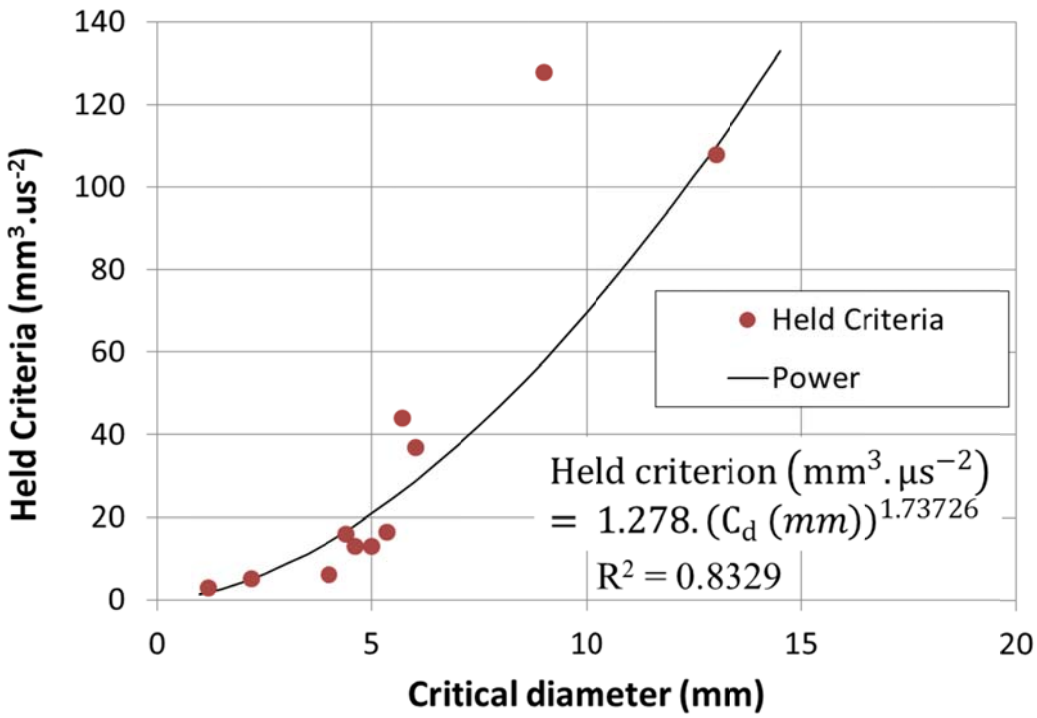

Figure 6. Held criteria vs. critical diameter correlation.

GAP TEST VERSUS DENSITY

Gap length versus density was investigated for five different explosives: TNT, CH-6, AP/Wax, PBX-9404 and Comp A-3. Very good correlations were obtained for all of the explosives when a single data source was used for a given explosive. Figure 7 gives an example of this, which is actually the same data used in a similar study [Price 1974]. However, when multiple data sources are used, the correlation is much weaker as seen for CompA-3 in figure 8 [Price 1974, Peterson 1981, Newman 1997] Several conclusions can be inferred from this study. Firsty, ingredients and processing can vastly change the shock sensitivity. Secondly, for a given explosive material and processing, a denser explosive will be less shock sensitive. This can be explained traditionally by the fact that a more porous explosive will have more or larger voids, so when a shock wave runs into the explosive, more or stronger hot spots will be set up in these voids. Thirdly, as it has been previously seen, the critical diameter typically increases when the gap length decreases so it should be logical that the critical diameter increases with the density for a given energetic material.

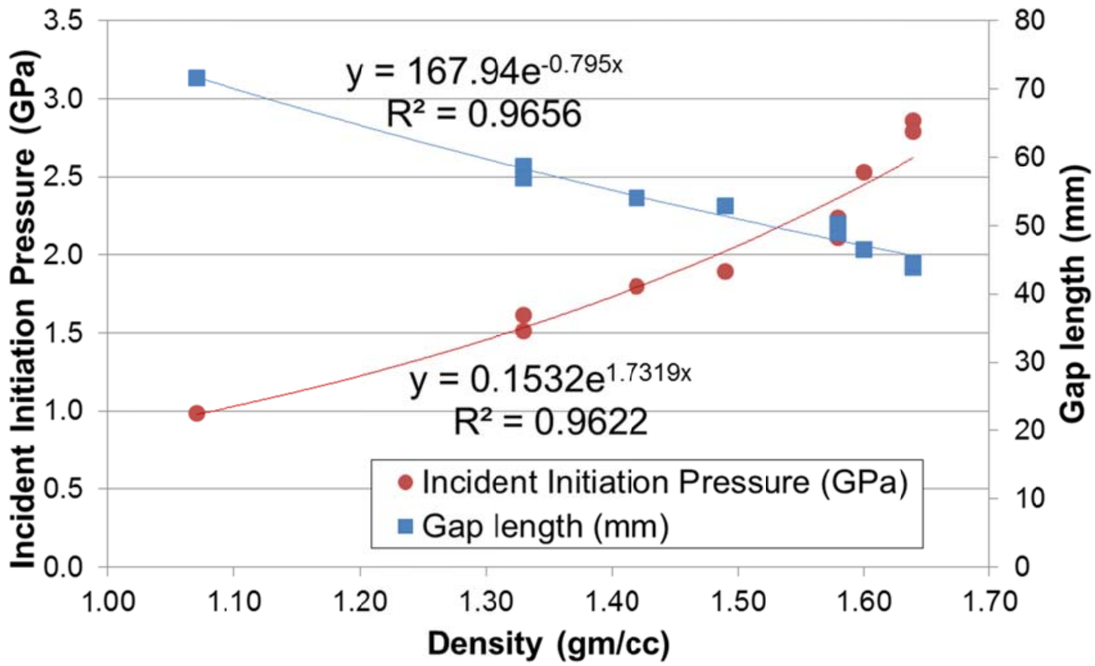

Figure 7. TNT NOL-LSGT density correlation for a single data source.

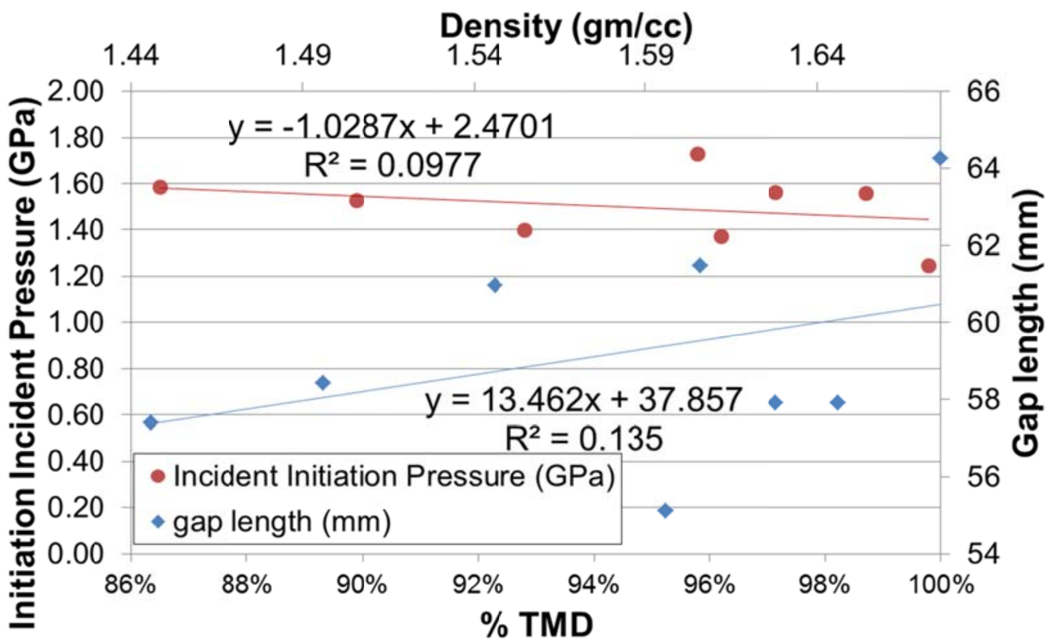

Figure 8. TNT NOL-LSGT density correlation using multiple data sources.

GURNEY ENERGY VERSUS GAP LENGTH AND CRITICAL DIAMETER

Gurney energy [22] has long been used as an explosive characteristic for the quantification of early work output of high explosives. The Gurney energy represents the kinetic energy per explosive mass resulting from the work performed by the expansion of the detonation products. Often, explosive work output is thought to correlate to sensitivity or the ability to detonate. For this reason, correlations of the Gurney energy with NOL-LSGT gap length and critical diameter were investigated. Figure 9 presents resulting plots from this investigation. From the plot, it appears clear that strong gap test and critical diameter correlations do not exist with the Gurney energy. A small trend of increased gap length with increased Gurney energy is potentially visible, but poorly correlated. No trend is observed for critical diameter versus Gurney energy. Patel [10] had already found a similar result with just eight explosives. This study, with twenty-four materials, supports the same conclusions. The study also investigated the the Figure of Insensitiveness of the Rotter Impact test, the detonation velocity and the detonation pressure. The Rotter figure of Insensitiveness, the detonation velocity and the detonation pressure characteristics did not provide any correlation relationship with the gap test results or critical diameter.

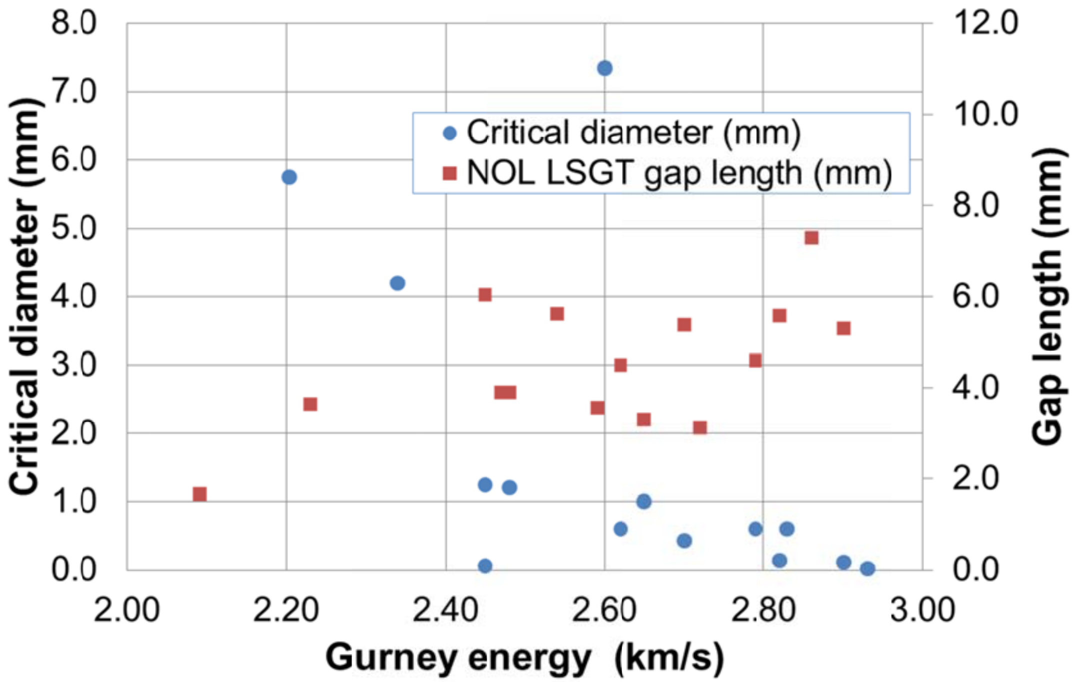

Figure 9. Critical diameter and NOL-LSGT gap length vs. Gurney energy.

CONCLUSIONS

We have conducted studies investigating laboratory test characteristics correlations. Correlations found included: NOL-SSGT to NOL-LSGT, NOL-LSGT to critical diameter, critical diameter to Held criteria and NOL-LSGT to density for a given explosive. Most of the correlations were not particularly strong. This seems reasonable, as none of the characteristics are definitively linked through fundamental physical processes. For example, extremely fine grained high explosives have been found to produce low shock sensitivity, yet have small critical diameters, counter to the overall trend. However, the NOL-LSGT to density correlations were very strong for data from a single explosive data source, presumably using similar ingredients and processing for all of the explosives. It is therefore clear, that ingredients and processing are important factors in resulting shock sensitivity and that porosity is normally fundamentally linked to shock sensitivity through hot spot initiation theory. The Rotter figure of Insensitiveness, the detonation velocity and the detonation pressure characteristics do not provide any correlation relationship with the gap test results or critical diameter. Most recently, NEWGATES has been modified to include an improved NOL small scale to large scale gap test correlation and critical diameter estimation calculations. It is important to realize that they only provide rough estimates, and should not be construed as accurate results.

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