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ABSTRACT

The two-dimensional Steven impact test has been developed to be reproducible and amenable to computer modeling. This test has a hemispherical projectile traveling at tens of m/s impacting a metal cased explosive target. To assist in the understanding of this safety test, two-dimensional shock wave gauge techniques were used to measure pressures of a few kilobars and times of reactions less than a millisecond. This work is in accord with a long-term goal to develop two-dimensional shock diagnostic techniques that are more than just time of arrival indicators.

Experiments were performed where explosives were impacted at levels below shock initiation levels but caused low level reactions. Carbon foil and carbon resistor pressure gauges were used to measure pressures and time of events. The carbon resistor gauges indicate a late time low level reaction at 350 µs after impact of the hemispherical projectile creating 0.5-6 kb peak shocks at the center of PBX 9501 (HMX/Estane/BDNPA-F; 95/2.5/2.5 wt %) explosive discs. The Steven test calculations are based on a ignition and growth criteria and found that the low level reaction occurs at 335 µs, which is in good agreement with the experimental data.

Some additional experiments simulating the Steven impact test were done on a gas gun with carbon foil and constantan strain gauges in a PMMA target. Hydrodynamic calculations can be used to evaluate the gauge performance in these experiments and check the lateral strain measurements.

INTRODUCTION

Impact sensitivity of solid high explosives is an important concern in handling, storage, and shipping procedures. Several impact tests have been developed for specific accident scenarios, but these tests are generally neither reproducible nor amenable to computer modeling. The Steven impact test[1] was developed with these objectives in mind. Blast wave overpressure gauges and external strain gauges were originally used to measure the relative violence of the explosive reactions. It became clear that that adding embedded gauges to the experiment would enhance understanding of the ignition of explosives in this test. This paper gives details of the embedded gauges in the test.

The Ignition and Growth reactive flow model previously tested several impact ignition criteria and simulated the growth of explosive reaction following ignition as the confined explosive charge is producing gaseous reaction products[2-3]. The best model from this work is used to model the experiments containing the imbedded gauges.

EXPERIMENTAL GEOMETRY

The experimental geometry for the Steven impact test is shown in Fig. 1. A 6.01 cm diameter steel projectile is accelerated by a gas gun into 11 cm diameter by 1.285 cm thick explosive charges confined by 0.3175 cm thick steel plates on the impact face and 1.905 cm thick steel plates on the back side. The original Steven test used a 6.01 cm diameter tantalum rod or rounded projectile.[1] DYNA2D calculations showed that the high explosive was driven to violent explosions by the frictional work done in the region where the tantalum projectile struck.[1] Since this objective of this study was to determine thresholds for low order reactions and to measure relative reaction violence of these

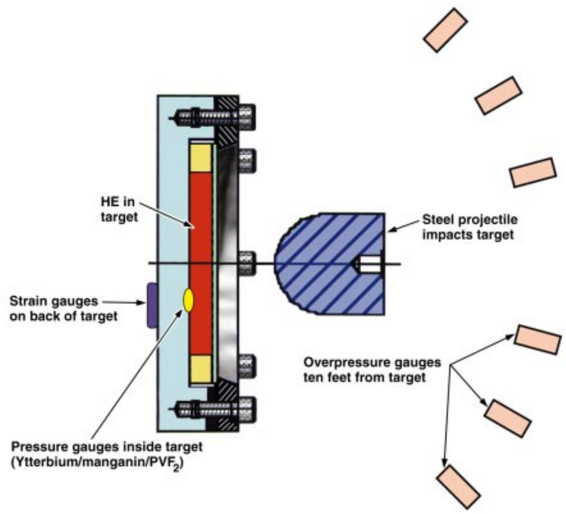

Figure 1**.** Schematic geometry of the Steven impact test

explosions, the projectiles were changed to steel to provide less frictional work on the explosive and to allow the 76.2 mm diameter gas gun to accelerate these projectiles to the higher velocities required to ignite LX-04 (HMX/Viton A; 85/15 wt%). Up to six external blast overpressure gauges were placed ten feet from each target for direct comparison with Susan test data. As shown in Fig. 1, a variety of embedded pressure gauges can be used to measure the internal pressure developed during the impact and the subsequent growth of reaction induced pressure if the critical impact velocity is exceeded. To date, only carbon foil and carbon resistor imbedded gauges have been used.

Figure 2 shows the placement of the carbon foil and carbon resistor gauges in the target. The carbon resistors were placed in slots that where machined into the top of the explosive cylinder. The carbon foil gauges were between two sheets of 0.125 mm thick Teflon. The Teflon extended over the entire diameter of the explosive. Later experiments eliminated the Teflon sheet and only placed a Teflon insulated gauge at the center.

The carbon foil gauge for one-dimensional longitudinal strain experiments[4-6] is good for 0-30 kb pressure with 5-10% accuracy and typical temporal resolution of 25-115 ns. Some two -dimensional flow experiments have been fired using carbon foil gauges where strain compensation on the pressure signals was attempted.[7] The carbon resistor gauge[5,7-10] is also good for one or two dimensional flow pressures of 0-30 kb with accuracy between 8-15 %. The temporal resolution of the carbon resistor gauge is 1.4 μs. It is a very rugged gauge that can be used in situations where the foil gauges will not survive. The accuracy decreases for the higher pressure values due to the non-linear calibration curve of the gauge. Both these gauges have large hysteresis on release of pressure, because they are porous materials that do not behave elastically.

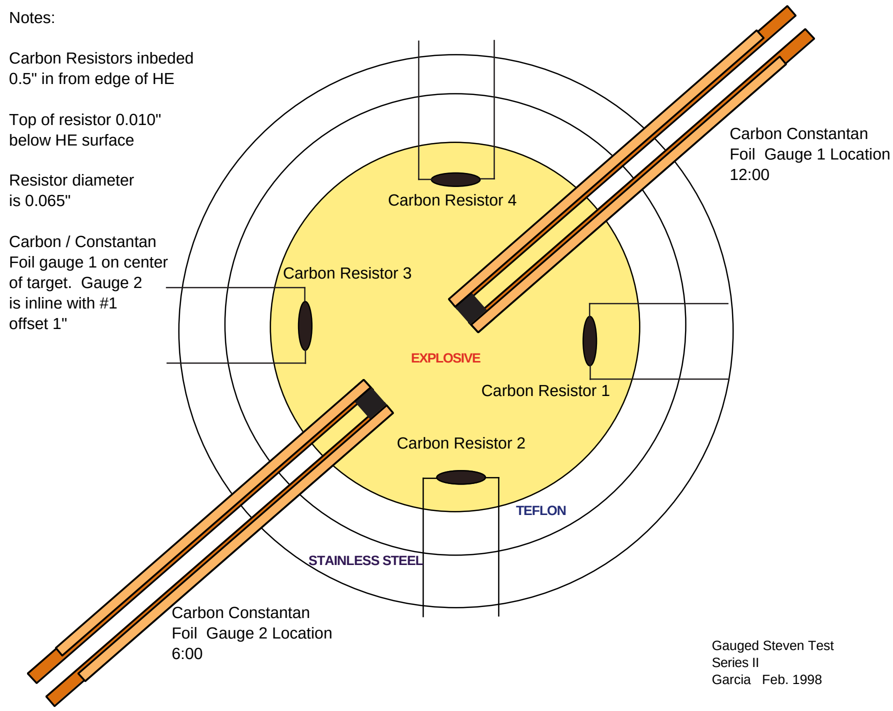

Figure 2. Cross-sectional view of the embedded gauges inside the target

For the foil gauges the lower time resolution was determined by assuming a 25-micron thick foil and the upper number assumed the foil gauge package to have insulation of 50-micron layers on both sides of it. [I.e. a total package thickness of 130 microns]. The resistor gauge is assumed to have 12.5-micron glue layer on both sides of it. To reach equilibrium it was assumed that the principal wave and its reflections transited the gauge element five times [roughly 4 1/2 times the package thickness] at a nominal velocity of 5 km/sec.

EXPERIMENTAL RESULTS

The pressure histories for PBX 9501 directly under the steel projectile from a carbon foil gauge are shown in Figure 3 for an impact velocity of 66.7 m/s. The record shows pressures below one kilobar lasting a number of microsecs. No indication of fast energy release from the explosive is seen on this gauge record.

Figure 4 shows a carbon resistor gauge with a build-up of pressure which peaks at about 350 μs after impact. A number of other experiments have been done but these will be reported at a later time when more analysis and modeling have been completed. It is estimated that the initial fraction reacted before rapid reaction ocurs is only about 0.1%.

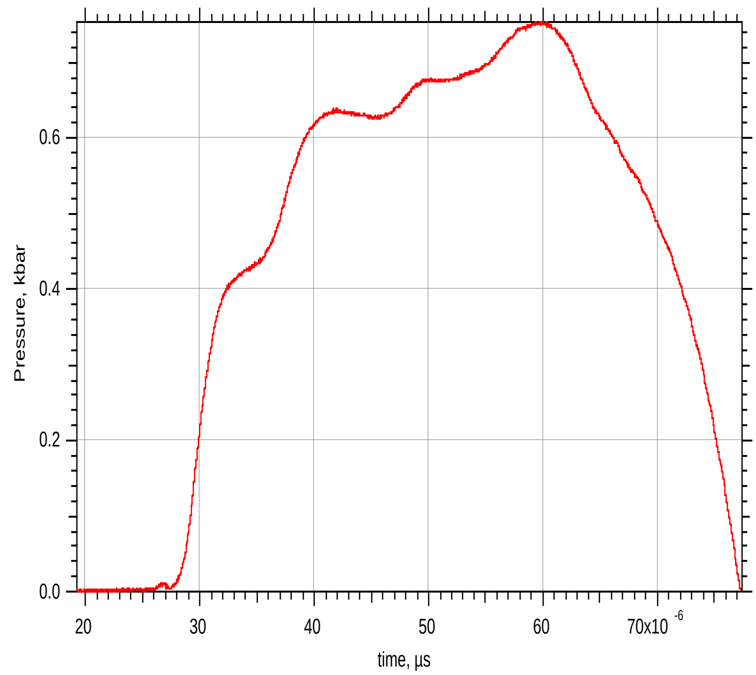

Figure 3. Pressure wave profile right at impact from the carbon foil gauge from experiment WRL-47 on PBX 9501

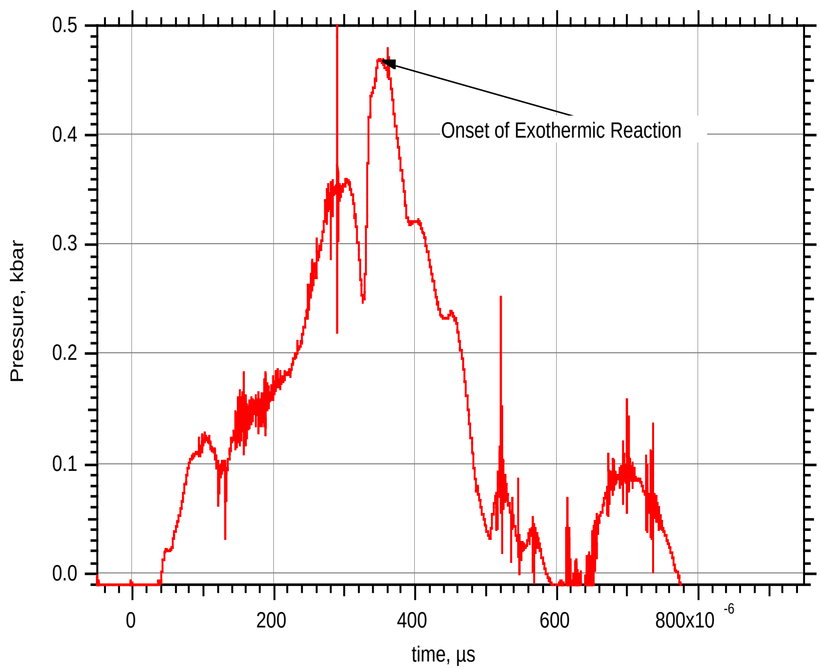

Figure 4. Record of a carbon resistor gauge on experiment WRL-47 on PBX 9501 showing that a late time reaction occurs at 350 µs.

INERT EXPERIMENTS WITH CARBON FOIL GAUGES

Two experiments were done on the 64 mm bore gas gun at Dynasen Corporation in which carbon foil gauges and strain gauges were placed inside PMMA targets, which were hit with a hemispherical projectile. Carbon foil pressure and constantan strain combined gauges (Dynasen C300-50-EKRTE) were used in one experiment. PVDF with constantan strain gauges (Dynasen PVF210-.125-EK) were used in the second experiment , which had more noise and is not reported here. The gauges were placed in an PMMA targets with front and back aluminum plates as shown in Fig. 5. The carbon foil stresses are shown in Figure 6 without strain compensation for a impact velocity of 0.192 mm/μs. The lateral strain component was measured in these experiments as shown in Fig. 7. These gauge records, along with two-dimensional hydrodynamic calculations will be used to determine the effect of lateral strain on the carbon foil gauge.

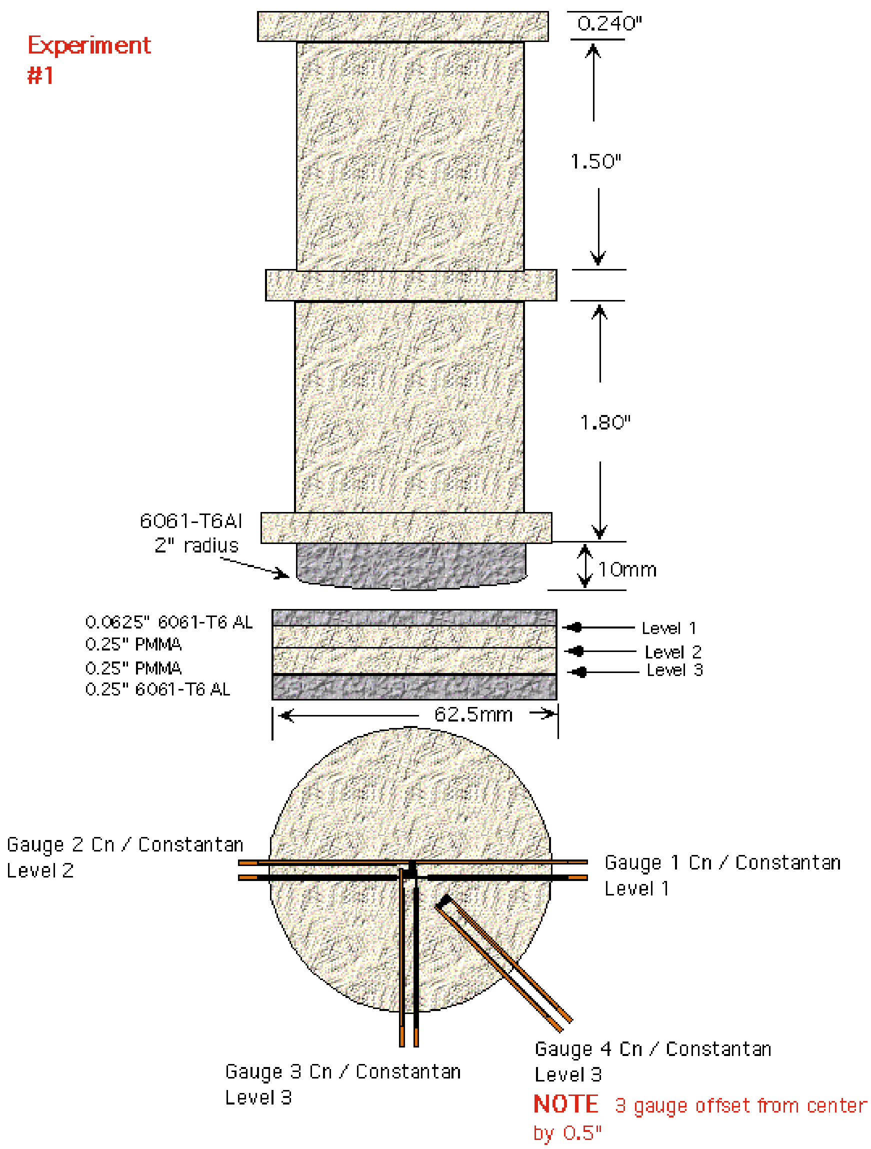

Figure 5. Schematic of 62 mm bore gas gun inert experiment with a hemispherical impactor onto a gauged target

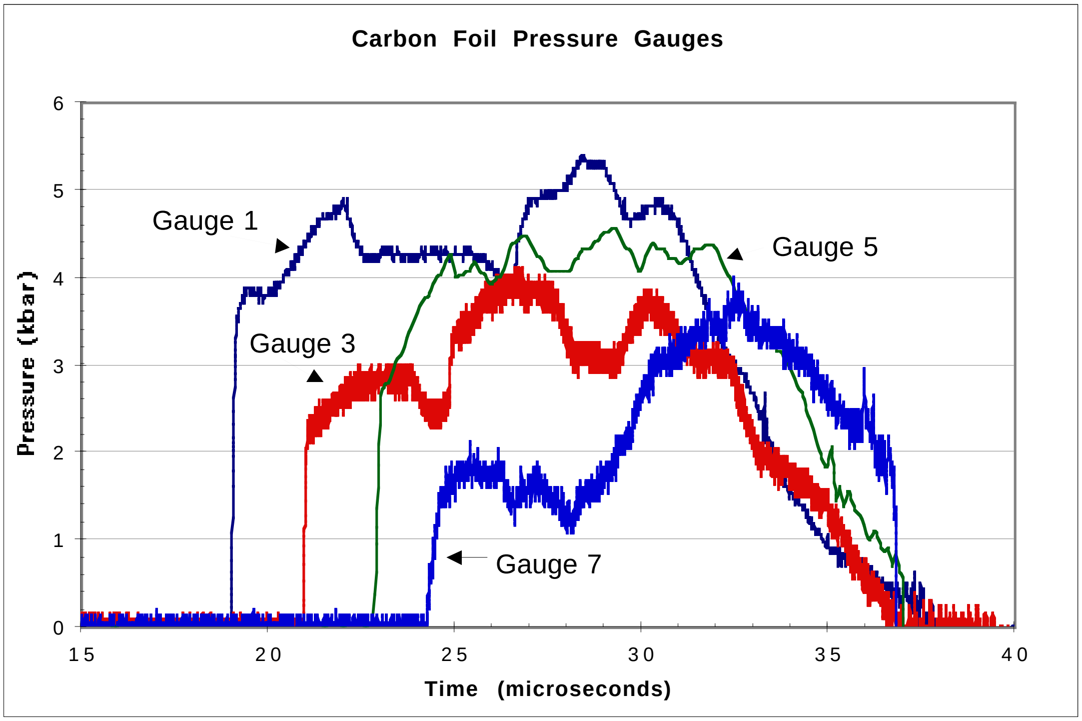

Figure 6. Carbon foil pressure gauges for 62 mm bore gas gun experiment

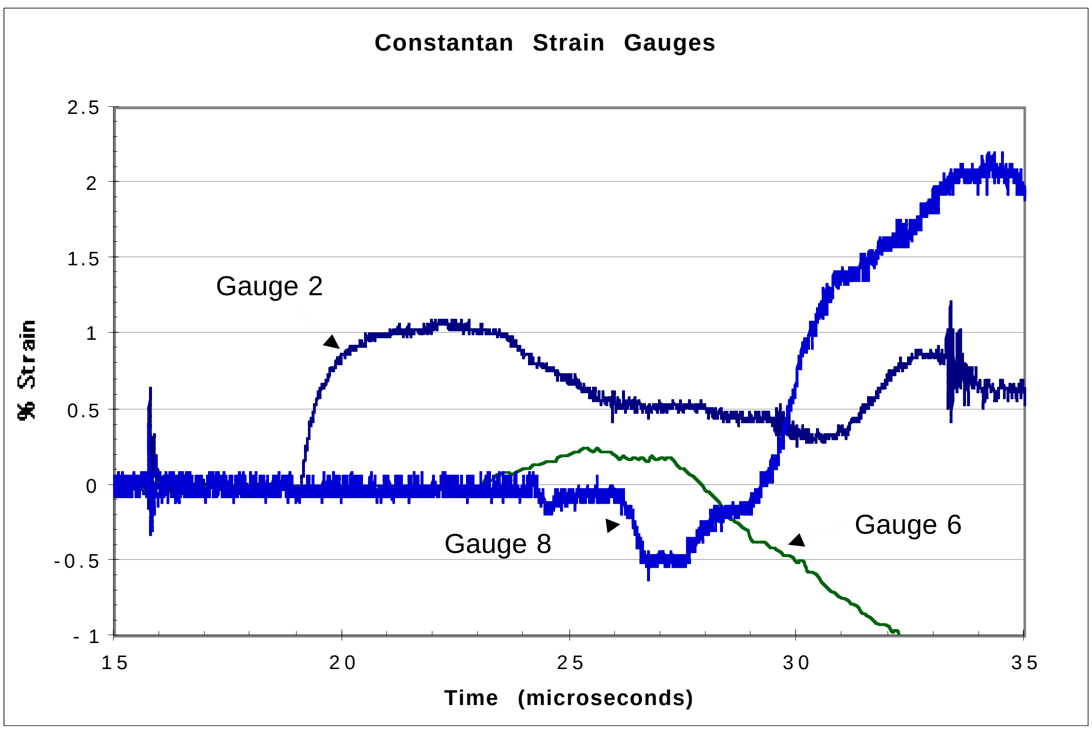

Figure 7. Strain gauge records from 62 mm gas gun experiment

IGNITION AND GROWTH REACTIVE FLOW MODEL

The first DYNA2D modeling of the Steven test[1] concentrated on its mechanical aspects. The measured depths of dents in the targets that did not react were accurately calculated, and a constant frictional work criteria for LX-10-1 was developed. Chidester et al.[2] then modified the Ignition and Growth reactive flow model developed for shock initiation and detonation to calculate reaction rates under impact ignition conditions. Fig. 8 show the embedded pressure gauge records for WRL-47 experiment along with the calculated results.[3] The carbon foil gauge located in the impact region measured a peak pressure and time duration very similar to the calculated values. Four carbon resistor gauges located near the outside of the explosive charge and the Teflon confining ring, along with framing camera data, detected a exothermic reaction at 350 µs after impact, in excellent agreement with the calculated time of 335µs. Therefore this Ignition and Growth model predicts quite well the measured impact pressure and pulse duration and the subsequent time to exothermic reaction. This gives confidence in being able to model similar situations that would be difficult to do experimentally. Note that the modeling provided the motivation for gauging a number of experiments to confirm the calculational results.

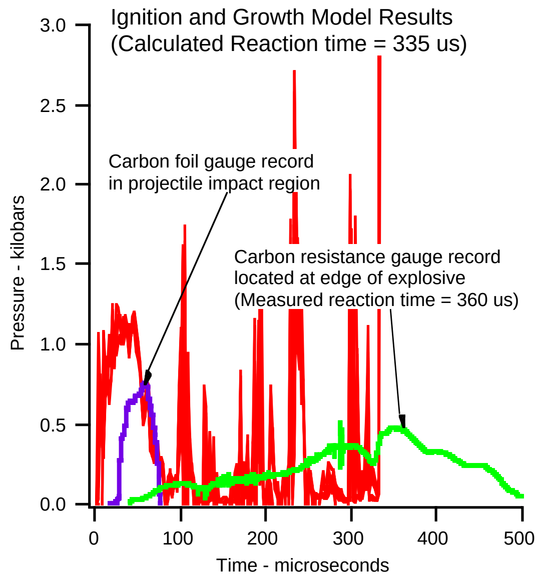

Figure 8. Comparison of embedded pressure gauge measurements and reactive flow calculations

SUMMARY AND CONCLUSIONS

Embedded carbon foil and resistor gauges gave pressure-time results for this test. The carbon resistor gauge is rugged but requires microsecs to come to equilibrium with its surrounding material. The long term carbon resistor pressure measurements are not sensitive to the two-dimensional flow that occurs in this experiment because the gauge smoothes out the differences giving only the change in resistance. The gauge data provides information that is important to understanding this low impact phenomenon.

Future work includes: (1) hydrodynamic code calculations to calculate lateral strain effects, (2) lateral strain will be measured with a strain gauge located near carbon foil active stress element, (3) an analysis of carbon foil gauge response to strain is needed, and (4) carbon resistor gauge needs to be calibrated at low pressures.

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