LA-UR-02-0353
*Approved for public release;
distribution is unlimited.*

Title:

X-0557 MODIFIED STEVEN TESTS: SERIES I and II

Author(s):

D. J. Idar, J. W. Straight, M.A. Osborn, W.L. Coulter, J. T. Mang and M. C. Anderson

Submitted to:

X-0557 MODIFIED STEVEN TESTS: SERIES I and II

D. J. Idar,[†] J. W. Straight,[††] M.A. Osborn,[††] W.L. Coulter,[††] J. T. Mang[†††] and M. C. Anderson[††]
[†]MS P918, [††]MS D411, [†††]MS C920
Los Alamos National Laboratory
Los Alamos, NM 87545

INTRODUCTION

Low-velocity mechanical impact leading to unintentional reaction is of concern in accident scenarios involving the handling, transport, and storage of high explosives (HE). These have been investigated using different experimental techniques, from small- to large-scale, including, but not limited to the drop weight impact, Taylor anvil impact, Susan,[1] and more recently, the Steven and Modified Steven tests.[2–8] Ideally, the data will be used to further advance 3-D finite element analysis predictive capability with improved bulk constitutive HE models for the assessment of HE response to mechanical insult. Our overall objectives for these experiments were to (1) evaluate the HE reaction threshold behavior for two different lots of X-0557, and (2) characterize the degree of reaction violence relative to a detonation. This report summarizes our single impact test results on the two different lots of X-0557 in Modified Steven targets.

EXPERIMENTAL

Two different lots of X-0557, with the same constituents as used in PBX 9501, were formulated in 1999 for these tests. The formulations were composed of a three-to-one ratio of the coarse to fine Class 1:2 grades of HMX; the Estane 5703 copolymer; an eutectic mixture of bis(2,2-dinitropropyl)acetal and bis(2,2-dinitropropyl)formal (either BDNPA-F or NP), and the free radical inhibitor, Irganox 1010. The lot numbers, compositional analyses, and average target densities are given in Table 1. The lots differ primarily in the BDNPA-F composition. Specimens of Lot 7287, 7 each, and Blend 99-02, 5 each, were machined from hydrostatically-pressed billets to the dimensions of 5.0-in. diameter by 0.5-in. thick.

Table 1: X-0557 Lot Compositional data

X-0557[†]	HMX wt%	Estane 5703 wt%	BDNPA-F wt%	Irganox 1010	Average density (g/cm^3)
Lot 7287	96.71	2.55	0.69	0.12	1.839
Blend 99-02	96.45	2.53	0.95	0.11	1.840

[†]Nominal PBX 9501 composition is 94.9/2.5/2.5/0.1 wt% HMX/Estane 5703/BDNPA-F/Irganox 1010 at 1.830 g/cm^3.

The basic target design is a modification of the design used in the original target series[6] and those used by Chidester et al.[2] The design, as depicted in Figure 1 and defined in Table 2, consisted of a holder, cover plate, and retaining ring. The X-0557 high explosive (HE) specimen was centered and covered with a 0.020-in. thick Sylgard 184 layer and the cover plate. The design allowed for an annular gap of 0.125-in. between the HE outer diameter (o.d.) and the holder inner diameter (i.d.). The targets were assembled and secured to a mild steel backing plate, 12.0-in. square by 3.0-in. thick with a 0.75-in. deep cavity, which served as a high-impedance boundary.

Table 2. Target design materials and dimensions

Cover Plate	Holder	Retaining Ring
304 stainless steel	A36 steel	A36 steel
0.118 ±0.001-in. thick	5.250 ±0.005-in. i.d.	4.500 ±0.005-in. i.d.
5.000 ±0.005-in. diameter	7.500 ±0.005-in. o.d.	7.500 ±0.005-in. o.d.
	0.638 ±0.002-in. deep	0.500 ±0.002-in. thick
	0.750 ±0.005-in. thick rear wall	

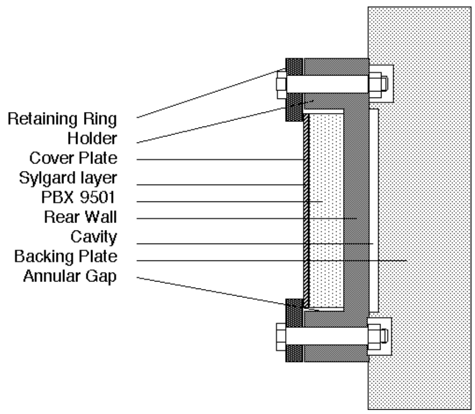

Figure 1. Basic Modified Steven target.

The spigot gun test design have been described previously.[6-8] Two kilogram, mild steel projectiles with a 3.0-in. diameter hemispherical nose were used for these tests. A cheap, easily replaceable light box/photodiode system was designed for determining the projectile velocity with three halogen lights, each with a corresponding photodiode. The data records yield three light profiles producing two independent velocity measurements. A polyvinylidene fluoride (PVDF) gauge was attached to the front surface of the target to record the projectile impact time and an additional data point, which averaged with the photodiode velocity data. Two MicroMeasurements EA-06-500BH-120 strain gauges were mounted on rear, target center surface to record the deformation relative to the time of impact. The two strain gauges were oriented with their elements at right angles to each other.

A ballistic pendulum and blast overpressure gauges were used to determine the violence of reaction relative to a PBX 9501 steady-state detonation. Pressure and timing calibrations were accomplished with four PBX 9501 calibration charges. The degree of pendulum displacement was measured using two independent passive measurements: the angular displacement of a friction pivot-arm, and the linear displacement of marker cable. Blast overpressure gauge data were obtained with two 0–200 psi transducers, in face-on mode positioned at 45˚ off of the projectile axis, at a distance of 10 ft from the front target face. Pendulum and blast gauge data were averaged to determine the energy release relative to a full detonation. Tests that did not result in a violent reaction of the HE were described as quenched and/or damaged.

RESULTS AND DISCUSSION

The X-0557 formulations are considerably more brittle in comparison to nomimal PBX 9501 due to the reduced fraction of plasticizer, increased fractions of HMX and Estane, and higher density subsequently resulting in loss of ductility. Steven tests and other types of impact tests results[1-9] have shown variations in the thresholds to high explosive violent reaction (HEVR) for HMX-based formulations as a function of binder type, weight fraction, and density variations. Based on the differences in formulations, we might anticipate changes in the threshold to HEVR in the Modified Steven test configuration as well.

Seven Lot 7287 targets and five Blend 99-02 targets were tested. The test numbers, projectile impact velocities, and average energy release data are provided in Table 3. Blast gauge records for test K8-3711 were not recorded; only the average of the pendulum data is reported here.

Table 3. X-0557 Test data

Test #	Test Date	X-0557 lot	Density (g/cm^3)	Projectile Velocity (m/s)	Test Result	Average Energy Release (%)
K8-4164	07/24/01	Lot 7287	1.840	37.3 ±0.9	Quenched	0
K8-4174	09/26/01	Lot 7287	1.836	39.0 ±0.9	Quenched	0
K8-4171	08/29/01	Lot 7287	1.837	41.6 ±1.0	HEVR	57.0 ±6.3
K8-3714	07/10/01	Lot 7287	1.839	42.6 ±1.0	HEVR	63.6 ±15.4
K8-3711	07/03/01	Lot 7287	1.840	47.1 ±1.1	HEVR	53.5 ±1.0[†]
K8-3708	06/11/01	Lot 7287	1.840	52.1 ±1.2	HEVR	69.4 ±8.2
K8-3705	04/11/01	Lot 7287	1.840	53.7 ±1.2	HEVR	69.1 ±10.4
K8-4186	10/11/01	Blend 99-02	1.840	38.6 ±0.9	Quenched	0
K8-4167	08/29/01	Blend 99-02	1.840	40.0 ±0.9	Quenched	0
K8-4183	10/03/01	Blend 99-02	1.840	40.9 ±0.9	Quenched	0
K8-4180	10/03/01	Blend 99-02	1.840	41.5 ±1.0	HEVR	56.9 ±9.6
K8-4177	09/26/01	Blend 99-02	1.840	44.0 ±1.0	HEVR	45.2 ±5.8

[†]Average of ballistic pendulum data only. Blast gauge records were not recorded for this test.

HEVR in these targets resulted in partial separation of the back wall from the radial side wall of the holder, and deformation to the retaining ring and cover plate with some evidence of burn/scorch marks apparent on the holders of selected tests. Both the physical damage and the highest average energy release for the X-0557 targets exceeded the baseline PBX 9501 test results.[8]

An examination of the strain gauge records provides additional insight regarding the reaction behavior (see Figure 2). The explosive initially behaves as an elastic-solid, transmitting force to the back plate upon impact. Near ~2000 microstrain, the explosive starts to crush and flow radially. The force levels off and then decreases as the explosive crushes filling the annular gap. Once the gap is filled the pressure on the crushed explosive begins to increase again, followed either by HEVR, or a rapid quenching of the reaction.

The threshold behavior (see Figure 3) for these targets demonstrates the same sharp consistency as seen with previous Modified Steven test series[6-8] with no evidence of mixed zone (crossover) results, i.e., no HEVR at lower velocities than the threshold, or quenched events at velocities that exceed the threshold. Threshold velocities ranged from ~39.0 to ~41.6 m/s and from ~40.9 to 41.5 m/s for the X-0557 Lot 7287 and Blend 99-02 targets, respectively. The overlap between the two X-0557 thresholds suggests that more significant differences in the plasticizer content from 0.69 to 0.95 wt% may be necessary to achieve discernable differences between threshold responses with the Modified Steven tests.

The X-0557 thresholds are lower than the new (1.827 g/cm^3) and baseline (1.830 g/cm^3) PBX 9501 threshold ranges of ~52.5 to 55.1 m/s, and ~54.4 to 55.9 m/s respectively with this same target and projectile test configuration. The reductions in the threshold velocity ranges are believed to be due to a combination of several factors resulting in changes to the mechanical property response of the HE to low velocity impact, i.e. 1) the effects of reduced plasticizer coupled with increased fractions of HMX and Estane, and 2) the higher density of the X-0557 targets relative to PBX 9501. The effect of increased density on low velocity mechanical loading test results were evaluated with lab-scale, quasi-two-dimensional target testing.[9] Results demonstrated that the higher density targets had a higher shear strain component than lower density targets of the same PBX. If the shear strain component is a key factor in the ignition mechanism as postulated by Scammon, et al.,[10] then a higher shear strain component would result in a reduced threshold range.

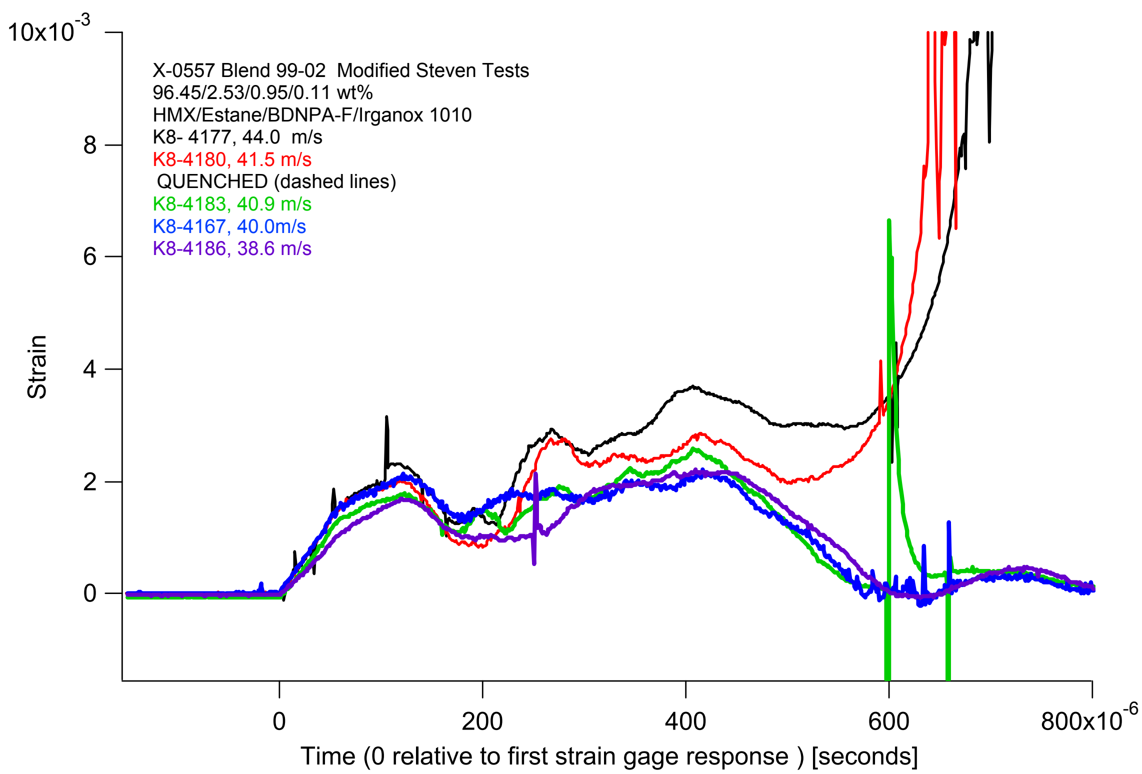

Figure 2. Examples of strain gauge records from the X-0557 Blend 99-02 tests. The solid lines represent strain records from tests that reacted violently. Strain records from tests K8-4183, -4167, and -4186, represented by the dashed lines, resulted in quenched reactions.

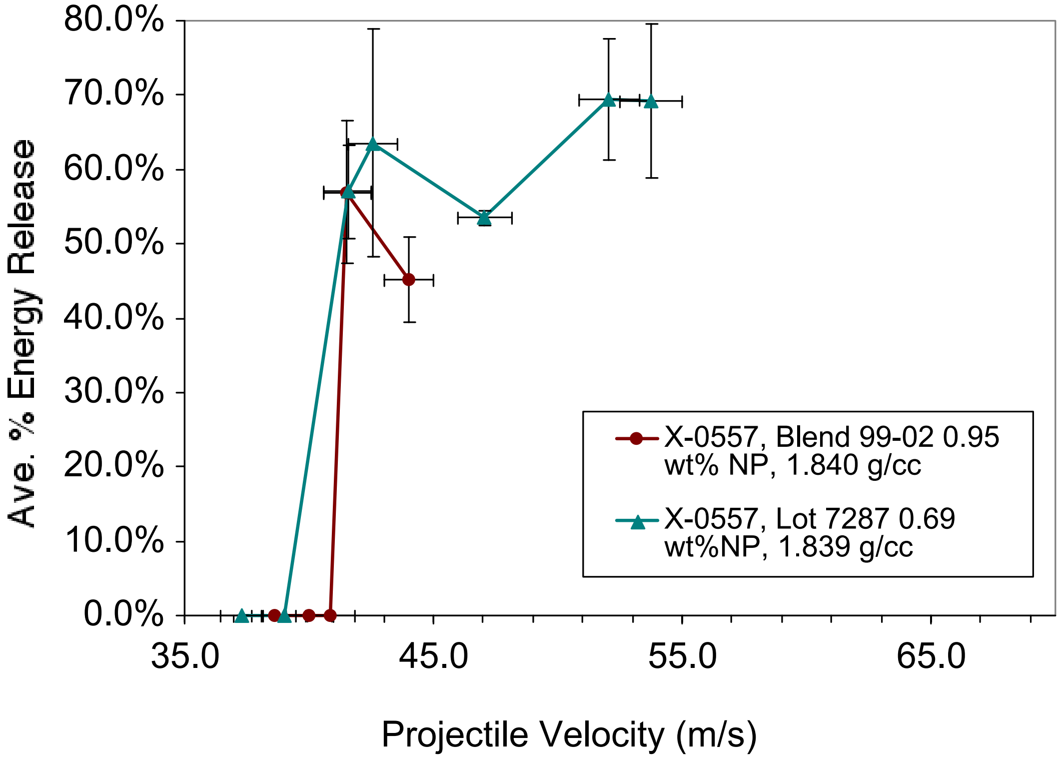

Figure 3: Threshold graph for the two X-0557 lots, Blend 99-02 and Lot 7287.

SUMMARY

The response of two X-0557 lots have been investigated using Modified Steven target designs. The violence of reaction, as measured by both passive and active techniques, is reported relative to a detonation in PBX 9501. The recorded violence was never equivalent to a complete detonation of the PBX 9501 and was always delayed relative to a prompt detonation. The highest average energy release was 69.4 ±8.2%, which is higher than the highest average energy release recorded for the baseline PBX 9501 target tests.[8] The threshold velocities for reaction and violence of reaction for two different lots of X-0557 were evaluated and compared. Test results demonstrated a remarkably sharp threshold to reaction without evidence of mixed zone results (crossovers). The X-0557 threshold ranges were lower than those previously measured for new and baseline PBX 9501 test results. This is believed to be due differences in composition and density resulting in changes in the mechanical response of the HE to low velocity impact.

Further work is required (1) evaluate the changes in threshold for X-0557 lot variations with different nitroplasticizer content between 0.95 and 2.5 wt%; and (2) to determine a semiquantitative relationship for the threshold behavior as a function of the different variables.

ACKNOWLEDGEMENTS

We gratefully acknowledge the support of the following groups in these research activities: DX-2 formulations and analytical team, ESA-WMM HE processing team, the JCI-NTS shop, the DX-5 technicians, the DX-5 designers and machinists, the DX-4 firing site support staff, and Aaron Honey, DX-3, for his image work and documentation.

REFERENCES

1. L. G. Green and G. D. Dorough, "Further Studies on the Ignition of Explosives," Fourth International Detonation Symposium, ARC-126, Office of Naval Research - Department of the Navy, Washington, D.C., pp. 477–486, 1965.

2. S. K. Chidester, L. G. Green, and C. G. Lee, "A Frictional Work Predictive Method for the Initiation of Solid High Explosives from Low-Pressure Impacts," Tenth International Detonation Symposium, Office of Naval Research, Arlington, Virginia, pp. 786–792, 1993.

3. S. K. Chidester, C. M. Tarver, and C. G. Lee, "Impact Ignition of New and Aged Solid Explosives," 1997 American Physical Society Topical Conference on Shock Compression of Condensed Matter, AIP Conference Proceedings 429, Woodbury, New York, pp. 707–710, 1997.

4. S. K. Chidester and C. M. Tarver, "Safety of Stockpile Aged Energetic Materials," 1998 Life Cycles of Energetic Materials Conference, Fullerton, CA, Mar. 29–Apr. 1, 1998.

5. S. K. Chidester and C. M. Tarver, "Low-Amplitude Impact Testing and Analysis of Pristine and Aged High Explosives," Eleventh International Detonation Symposium, Snowmass, CO, Aug. 31–Sept. 4, 1998.

6. D. J. Idar, R. A. Lucht, R. J. Scammon, J. W. Straight, and C. B. Skidmore, "PBX 9501 High Explosive Violent Response/Low Amplitude Insult Project: Phase I," Los Alamos National Laboratory report LA-13164-MS, Los Alamos, NM (January 1997).

7. D. J. Idar, R. A. Lucht, J. W. Straight, R. J. Scammon, R. V. Browning, J. Middleditch, J. K. Dienes, C. B. Skidmore, and G. A. Buntain, "Low Amplitude Insult Project: PBX 9501 High Explosive Violent Reaction Experiments," Eleventh International Detonation Symposium, Snowmass, CO, Aug. 31–Sept. 4, 1998, pp. 101-110.

8. D. J. Idar, J. W. Straight, M. Osborn, C. B. Skidmore, D. S. Phillips, and G. A. Buntain, "PBX 9501 High Explosive Violent Reaction: Phase II Baseline And Aged Experiments," Los Alamos National Laboratory report LA-13641-MS, Los Alamos, NM (April 2000.)

9. B. W Asay, P. M. Dickson, B. Henson, C. S. Fugard, D. J. Funk and D. J. Idar, " "Dynamic Measurement of the Influence of Projectile Radius and Velocity on Strain Localization During Impact of an Energetic Material," Eleventh International Detonation Symposium, Snowmass, CO, Aug. 31-Sept. 4, 1998, pp. 781-787.

10. R.J. Scammon, R.V. Browning, J. Middleditch, J. K. Dienes, K. S. Habermam, and J. G. Bennett, "Low Amplitude Insult Project: Structural Analysis and Prediction of Low Order Reaction,: Eleventh International Detonation Symposium, Snowmass, CO, Aug. 31-Sept. 4, 1998, pp. 111-118.