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Modified Steven Tests of Artificially Aged PBX 9501

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Abstract

The Modified Steven test geometry was used to investigate the low velocity impact behavior and response of artificially aged PBX 9501. The tests were designed to probe the effect that a decrease in the molecular weight (M_w), of the binder component Estane 5703, has on the low velocity impact threshold for violent reaction. High explosive targets were pressed and machined to the desired size specifications and then aged for different periods of time in temperature and humidity controlled chambers. Threshold velocities for four different units of aged PBX 9501, representing different levels of Estane degradation, were measured and compared to baseline measurements of pristine PBX 9501.

Introduction

Low-velocity mechanical impact leading to unintentional reaction is of concern in accident scenarios involving the handling, transport, and storage of high explosives. While pristine PBX 9501 has been well characterized by low velocity impact tests [1-3], aged materials have not been thoroughly characterized [4,5]. A potential aging mechanism of PBX 9501 is the decrease of the molecular weight, due to chain scission, of Estane. A reduction of molecular weight has been shown to adversely affect the mechanical properties of PBX 9501 [6,7], though little is known about how this might affect high explosive (HE) sensitivity.

The Modified Steven test is a low velocity impact test. It provides a measure of the sensitivity of a material in that an impact velocity threshold for high explosive violent reaction (HEVR) and the relative (to an intentional target detonation) violence of the reaction are measured. The results are specific to the test configuration and depend upon a number of variables, including HE composition, density and porosity as well as impactor geometry and the degree of confinement. Low velocity impact tests have been used to investigate the mechanical loading behavior and response of baseline [1-3] and nitroplasticizer (NP)-depleted [4,5] (another aging mechanism) PBX 9501 lots, as well as other HMX-based formulations [8]. For the NP-depleted studies, it was found that the velocity threshold for HEVR decreased quadratically with decreasing NP [4,5,9].

Here we present the results of Modified Steven tests on artificially (massively) aged PBX 9501. Four different units of aged PBX 9501, which differ in average M_w of Estane, were studied. Our objectives for these experiments were to evaluate the HE reaction threshold behavior as a function of M_w and to characterize the degree of reaction violence.

Experimental

Spigot gun design, mount, and characterization tests

The spigot gun design, mount, and characterization tests have been described previously [1-3]. Two kilogram mild steel projectiles, with a 3.0-in. diameter hemispherical nose, were used for these tests.

Target designs

The basic target design started as a modification of the target assembly used in the original target series[1] and those used by Chidester et al.[10] The design, as depicted in Figure 1, consisted of a holder, cover plate, and retaining ring. The PBX 9501 high explosive 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 and the holder inner diameter. 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.

Artificially-aged PBX 9501

PBX 9501 was formulated, pressed and machined into disks, 5" in diameter and 1/2" thick at PANTEX for use in the Modified Steven tests. PBX 9501 is composed of HMX (a three-to-one ratio of the Class 1:2 grades), Estane 5703, a 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 disks were placed inside specially designed "aging cans" held at 70°C and 74% relative humidity in order to promote degradation of the M_w of Estane. The interior walls of the aging cans were coated with nitroplasticizer in order to mitigate NP loss from the binder. Five units of aged PBX 9501, consisting of five disks each, and aged between 74 and 433 days, were delivered to Los Alamos National Laboratory (LANL) for testing purposes (Table I). As seen in the table, significant degradation of the Estane molecular weight occurred after only 74 days of aging.

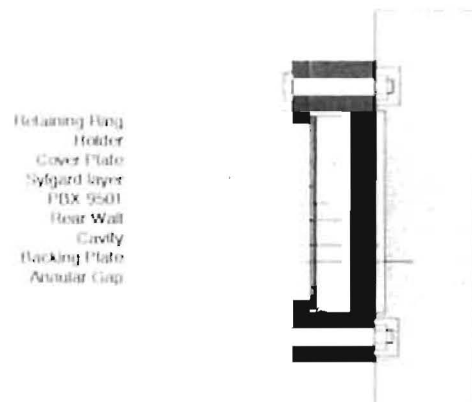


Figure 1: Basic Modified Steven target

Diagnostics

A light box photodiode system was used for determining the projectile velocity. Three halogen lights, each with a corresponding photodiode, were spaced at three-inch intervals in a wooden frame for this purpose. 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. The impact timing provides an additional data point to evaluate the projectile velocity. This datum is averaged with the velocity data from the photodiode box.

Two MicroMeasurements EA-06-500BH-120 strain gauges, amplified with Vishay model 2311 signal conditioners, were mounted on center of the target's rear 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.

Table I: Average M_w of Estane and Target Densities of Aged Units

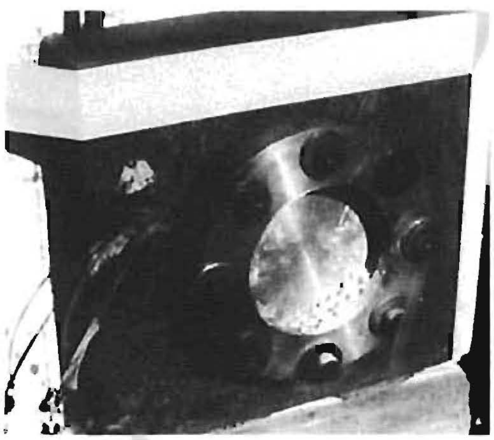
Unit	Days Aged at 70°C and 74% RH	M_w (kD)*	Mean Density of HE Target (g/cm^3)
1	74	20.90	1.829 ± 0.001
2	136	7.00	1.829 ± 0.001
3	178	4.08	--
4	220	3.44	1.830 ± 0.001
5	433	3.55	1.826 ± 0.003

* M_w of new Estane ~ 100 kD

A ballistic pendulum and blast overpressure gauges were used to evaluate the energy release relative to a PBX 9501 steady-state detonation [11]. 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 (~3.05 m) 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

Five targets each from Units 1, 3, 4 and 5 were tested [12]. Thirteen of the twenty targets reacted violently, and six targets were damaged and quenched. One test result was classified as a partial. The shot numbers, average M_w, projectile impact velocities, and average energy release data are provided for comparison in Table II.



a)

b)

Figure 2: a) Modified Steven target following an HEVR (shot K8-6737; 63 m/s, E ~ 13%) b) PBX 9501 fragments recovered from the firing mound

Violent reactions resulted in complete removal of the cover plate from the target assembly. Cover plates that were retrieved were significantly deformed. The inside surface of the holder and the retaining ring were found to be significantly deformed at the highest impact velocities, only. Inspection of the firing mound following an HEVR typically yielded large HE fragments (1-2" in length). HE fragments were also found in the sample holder (Figure 2) and on three separate (Table II) occasions this remaining HE ignited and burned immediately following the HEVR event. These were the first instances of this behavior for the Modified Steven test.

Table II: Impact Velocity and Average Energy Released in an HEVR

Shot #	Unit	M_w (kD)	Impact Velocity (m/s)	Energy Release (%)
K8-6054	1	20.90	49 ± 1	0
K8-6051	1	20.90	55 ± 1	0
K8-6048	1	20.90	57 ± 1	15 ± 1
K8-6057	1	20.90	60 ± 1	10 ± 2[‡]
K8-6075	1	20.90	110 ± 3	36 ± 7
K8-6060	3	4.08	52 ± 1	0
K8-6063	3	4.08	59 ± 1	8 ± 1[‡&]
K8-6069	3	4.08	61 ± 1	9 ± 1*[‡]
K8-6066	3	4.08	62 ± 1	14 ± 2
K8-6072	3	4.08	105 ± 2	48 ± 6
K8-6734	4	3.44	56 ± 1	0
K8-6743	4	3.44	59 ± 1	0
K8-6740	4	3.44	60 ± 1	20 ± 2
K8-6737	4	3.44	63 ± 1	13 ± 2
K8-6746	4	3.44	105 ± 2	34 ± 2
K8-6974	5	3.55	54 ± 1	0
K8-6971	5	3.55	56 ± 1	12 ± 3
K8-6979	5	3.55	63 ± 1	11 ± 5[‡]
K8-7291	5	3.55	65 ± 1	15 ± 1*
K8-7294	5	3.55	110 ± 3	61 ± 9

* No blast gauge data
[‡] HE burned brightly
[&] partial

Quenched tests resulted in the simple indentation of the cover plate as a result of the projectile impact. The target remained intact an attached to the backing plate. The term "quenched" is used to describe these results as post-test examination of previous shots has shown evidence of reaction that was mitigated before an explosion resulted. In shot K8-6063, a low level of energy release was measured by the ballistic pendulum, but the cover plate was not completely removed from the target. As this result was qualitatively different from both an HEVR and a "quenched" result, it was classified as a "partial" reaction.

An examination of the strain gauge records provides additional insight regarding the reaction behavior. Representative strain gauge records are shown in Figure 3 and display the typical behavior for the Modified Steven test. The explosive initially behaves as an elastic-solid, transmitting force to the back plate. Near ~2000 microstrain at the back plate, the explosive starts to crush and flow radially. The force levels off and then starts to decrease as the explosive crushes until the annular gap is filled, after which, the pressure on the crushed explosive begins to increase again.

Velocity Threshold

Figure 4 shows a plot of the velocity threshold data measured for all four units. In all cases, the threshold behavior demonstrated the same sharp behavior as seen with previous Modified Steven test series[1-5]. No evidence of mixed zone (crossover) results, i.e., violent reactions at lower velocities than the threshold, or nonviolent events at higher velocities that exceed the threshold was found. As seen by the tight grouping of the points, all units showed a similar velocity threshold for violent reaction. Figure 5 shows a plot of the measured velocity threshold as a function of the average M_w of Estane, where the data point at ~ 100 kD represents unaged Estane and thus pristine PBX 9501. As seen in the figure, there is no significant change in the velocity threshold (as measured by the Modified Steven test) for HEVR, as a function of the average molecular weight of Estane.

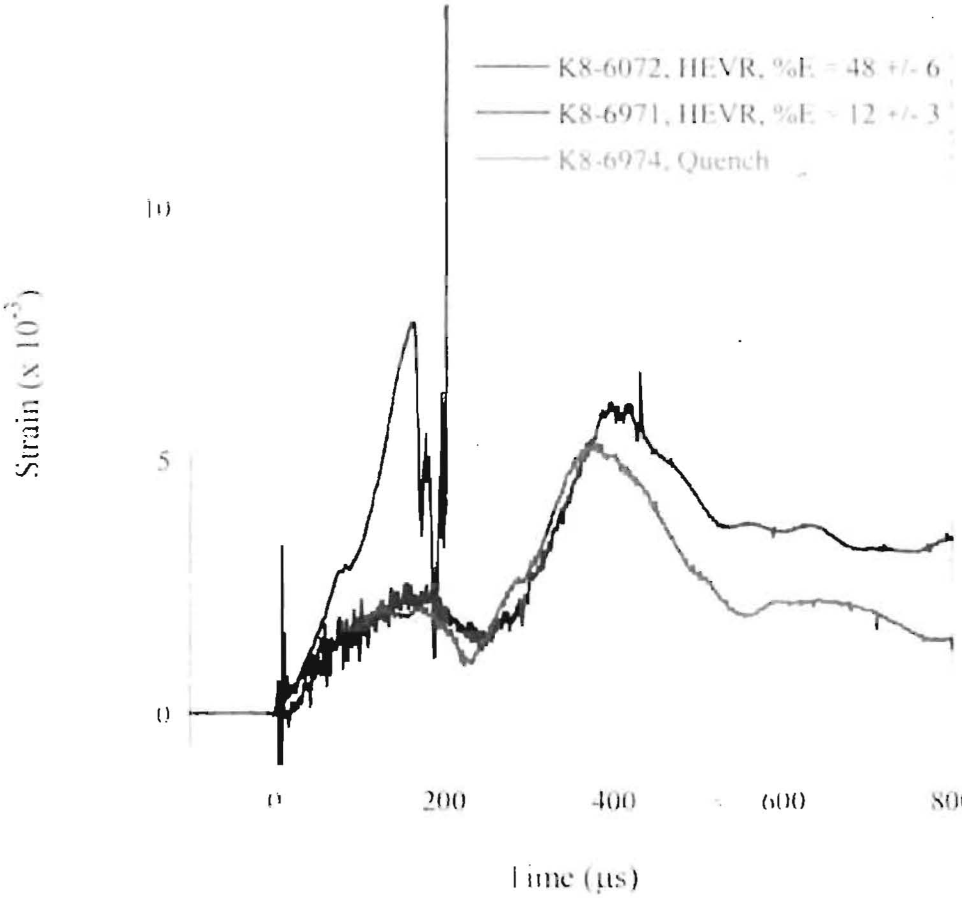


Figure 3: Strain gauges records from backside of target

Energy Release

While we have found no significant change in the velocity threshold for HEVR as a function of M_w, changes in the relative energy release, of an HEVR, have been seen. Near the threshold, we have measured smaller energy releases (~ 8%) than have been previously seen. Mechanical testing has indicated that the aged PBX 9501 is weaker and less ductile than pristine PBX 9501 and hence is reduced to rubble more readily [6,7]. This reduction to rubble may hinder energy transfer and the development of shear bands (an important ignition mechanism in this geometry), thus leaving more unreacted high explosive.

Above the threshold, as seen in the Figure 4, the relative energy release shows a dip, unlike pristine PBX 9501, which shows a broad plateau followed by a gradual increase in energy release. Interestingly, this dip has also been observed in studies of other aging mechanisms [4,5,9].

At our fastest impact velocity, the energy release is significantly higher (~ 61% for unit 5) than pristine material, much like Modified Steven tests of low-NP materials [4,5,9]. At the fastest impact velocities there is higher energy input, which can cause more extensive rubble. The rubble

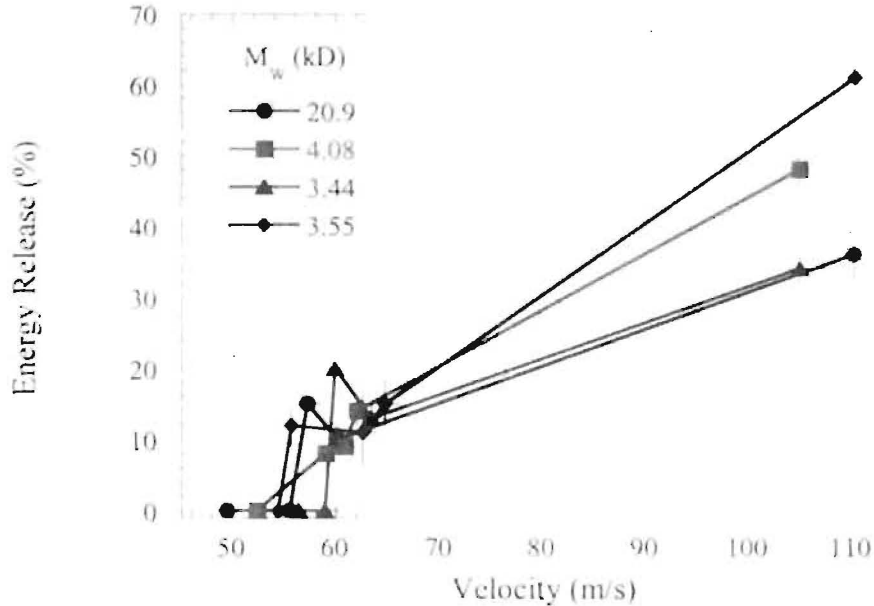


Figure 4: Velocity thresholds for Units 1, 3, 4 and 5 determined by the Modified Steven test.

will expose more surface area for reaction and at the same time may act to trap the evolving gases and thus give a higher energy output.

Summary

The response of aged PBX 9501 has been studied using the Modified Steven test. Machined targets of PBX 9501 were aged at elevated temperature and humidity for different lengths of time in order to simulate aging of the binder. The average molecular weight (M_w) of the Estane component of the binder was found to decrease dramatically over the course of the study (433 days) from ~ 100.5 kD to 3.55 kD, suggesting significant chain scissioning had occurred.

Four units of PBX 9501, differing in the average molecular weight of Estane were investigated in order to determine the velocity threshold for HEVR and the energy released in such an event. No significant shift in the velocity threshold was found as a function of the molecular weight of Estane and hence aging time. All thresholds were within the expected limits for pristine PBX 9501.

The aged units did show different levels of energy release than pristine PBX 9501. Excess PBX 9501 remaining in the target after an HEVR was seen to burn on three separate occasions. Near the velocity threshold, unusually low energy releases were measured and above the threshold, a decrease in energy release was observed with increasing impact velocity. Such a behavior has been seen in other artificially aged materials. The highest energy release of 61% measured for Unit 5 was significantly higher than that measured for new PBX 9501 and again similar to what has been seen for other aged materials.

Acknowledgements

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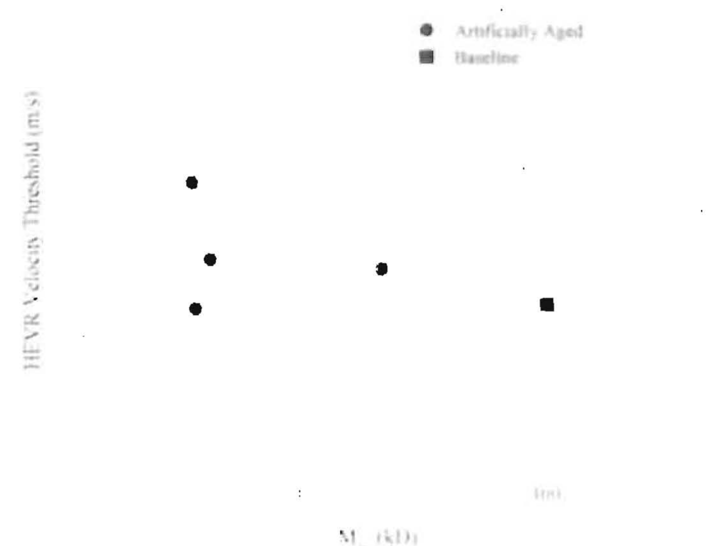

Figure 5: HEVR velocity threshold as a function of the molecular weight of Estane.

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