CONF-950846-59

LA-UR- 95-2956

Title: MEASUREMENT OF THE STRESS/STRAIN RESPONSE OF ENERGETIC MATERIALS AS A FUNCTION OF STRAIN RATE AND TEMPERATURE: PBX 9501 AND MOCK 9501

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Submitted to: 1995 Topical Conference -- Shock Compression of Condensed Matter
August 13-18, 1995
Seattle, WA

Los Alamos
NATIONAL LABORATORY

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Measurement of the Stress/Strain Response of Energetic Materials as a Function of Strain Rate and Temperature: PBX 9501 and Mock 9501

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We have measured the stress/strain behavior of PBX 9501, Mock 900-21 and two new mocks consisting of monoclinic granular sugar embedded in (1) a BDNPA-F/estane binder (a 9501 material mock; a hard organic crystal embedded in a plastic) and (2) neat estane (an LX-14 mock) at strain rates from 10^{-3} to 10^{-1}, at two L/D's and at two temperatures (25 and 60 C). We find that the compressive strength falls with increasing temperature and rises with increasing strain rate. We also find that the new 9501 sugar mock most closely resembles the behavior of the 9501 explosive and differences may be attributable to the different ages of the estane binder used.

INTRODUCTION

It is difficult to experimentally measure the mechanical response of high explosive under every conceivable impact geometry and velocity. The development of real engineering models, however, can assist the analyst in determining credible probabilities for use in determining overall risk in accident scenarios. Presently, few data exist on the mechanical properties of Plastic Bonded eXplosives (PBX, in particular PBX 9501),[1] and no accurate constitutive model exists for these composite materials covering strain rates from 10^{-3} to 10^{4}, i.e. those rates at which accidental scenarios are most credible. We have begun initial studies of the stress/strain response of composite energetic materials to fill in this void and to provide data for the determination of accurate constitutive constants. In particular, we have measured the compressive stress/strain behavior of PBX 9501, Mock 900-21 and two new mocks consisting of monoclinic granular sugar embedded in a BDNPA/estane binder (a 9501 material mock; a hard organic crystal embedded in a plastic binder) and neat estane binder (an LX-14 mock), at rates from 10^{-3} to 2.2×10^{-1}, at two L/D's, one and two, and at two temperatures (25 and 60 C). We have also investigated a new material mock that we hope will simulate the constitutive behavior of the neat PBX without the added difficulty of chemical reaction. This will give us the ability to examine how the mechanical properties of the explosive enhances or inhibits chemical energy release by studying the differences in results obtained between experiments conducted with inert mock and with real explosive.

EXPERIMENTAL

All compressive tests were performed on an Instron 1123 test frame using a 1000 lb. load cell. The platens were fabricated from steel and polished to a mirror finish. For each test, the samples and platens were lubricated with moly paste to eliminate frictional effects between the face of the platen and the sample causing barreling of the samples. We found that barreling was significant at even moderate strain rates of 1 s^{-1} and we report results only in the regime where barreling was negligible (< 0.22 s^{-1}). Extension measurements were made simultaneously with stress measurements. The resulting stress and extension voltages were digitized using a LeCroy 9400A oscilloscope and transferred to a Macintosh Powerbook for analysis via GPIB. Samples were machined right-regular cylinders of 0.375" diameter. Sample and chamber temperatures were controlled by conduction through the platens which were equipped with ports for running heating/cooling fluids through them. The temperature of the chamber was controlled using a Neslab water circulator and by monitoring the temperature of the platens which were equipped with type K thermocouples (Omega). The platens and sample were isolated from ambient temperature by enclosing them with insulating foam. The temperature histories of the mock explosives were monitored and the time to temperature equilibrium was measured for samples placed in the chamber from room temperature. The explosive and mock samples were loaded and allowed the full "equilibrium" time prior to testing. Temperatures were accurate to ± 2 C and the extensometer was calibrated (at temperature) while enclosed in the test chamber. Table I lists the composition, strain rates, L/D's, and temperatures of the samples tested. At least three tests were performed for each material and at each strain rate and temperature studied. The new mocks were made with granular sugar (C&H) that has a particle size distribution that closely matches the particle size distribution found in PBX 9501.

RESULTS

Shown in Fig. 1 are the compressive stress-strain curves obtained for PBX 9501 at a fixed L/D of 2, strain rates from 10^{-3} to 10^{-1}, and at 25 and 60 C. We notice immediately that the ultimate stress is lower by nearly a factor of two and that the strain at which this occurs is less for the 60 C samples than for the 25 C samples.

TABLE I.

Material	Composition	L/D's Ø=.375"	Temp(C)	Rates
PBX 9501	95% HMX, 2.5% estane 2.5% BDNPA-F	1,1.5 2	25 60	1e-3 to 1e-1
Mock 900-21	44.65 % $Ba(NO_3)$, 49.35% pentek 3.00 % estane, and 3.0% BDNPA-F	1,2	25 60	1e-3 to 1e-1
PBS 9501	95% C&H sugar, 3.0% estane 3.0% BDNPA-F	1,2	25 60	1e-3 to 1e-1
PBS LX-14	94.55% C&H sugar, 5.45% estane	1,2	25 60	1e-3 to 1e-1

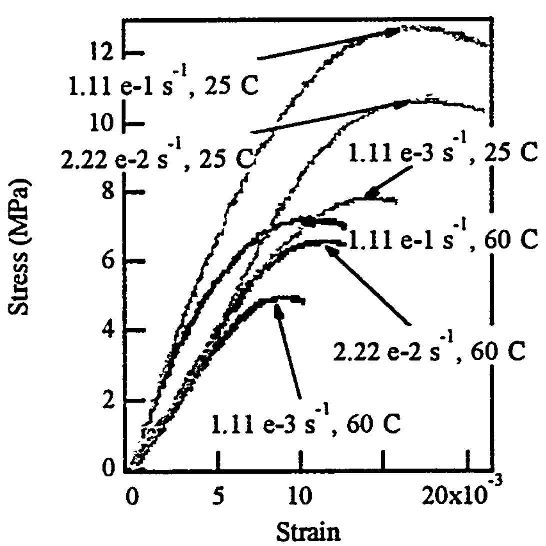

FIGURE 1. Sress-strain curves of PBX 9501 as a function of strain rate and temperature.

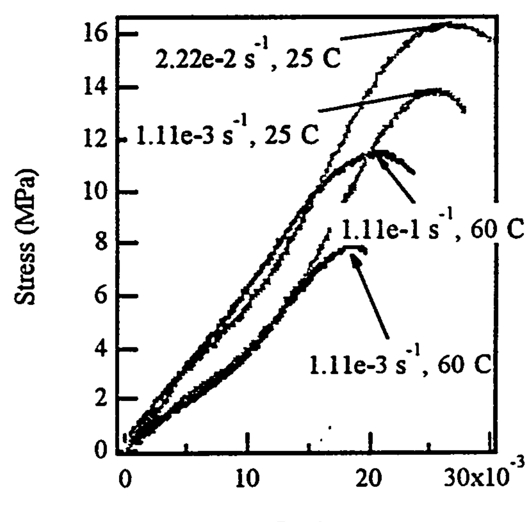

FIGURE 2. Stress-strain curves of Mock 900-21 as a function of strain rate and temperature.

Since we expect the organic crystalline HMX to change very little with temperature, these changes are indicative of softening of the plastic BDNPA/estane binder, and are not surprising. We also note that the ultimate strength increases as a function of strain rate indicating the strong dependence of these materials on strain rate. Shown below in Figs. 2-4 are the corresponding stress-strain curves for Mock 900-21, Plastic Bonded Sugar (PBS) 9501, and PBS LX-14.

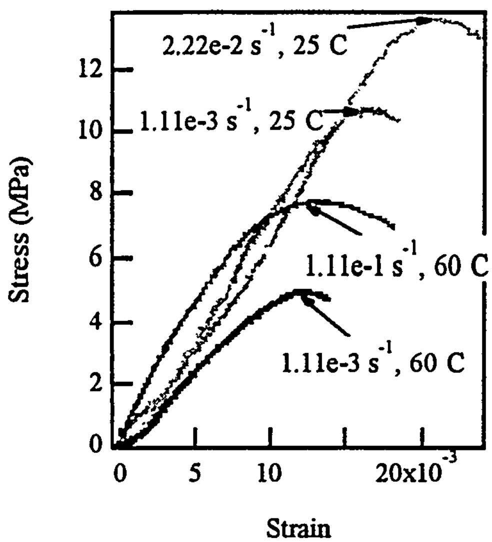

FIGURE 3. Stress-strain curves of PBS 9501 as a function of strain rate and temperature.

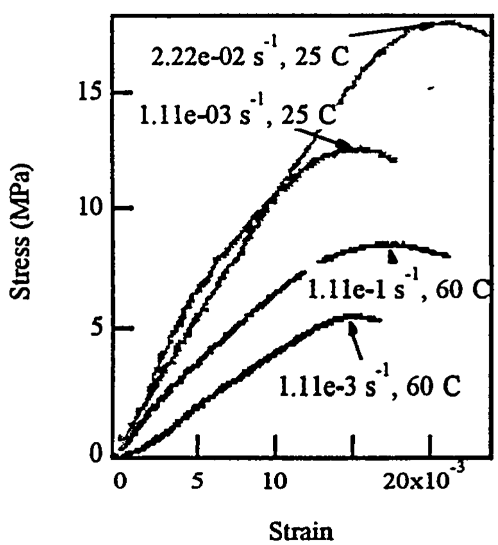

FIGURE 4. Stress-strain curves taken for PBS LX-14 as a function of strain rate and temperature.

As observed in the figures, we obtain similar results for all of the materials, i.e. reduced strength at higher temperatures, and greater strength at higher strain rates. We also note that the 900-21 density and strength mock exhibits some work hardening behavior that is not observed in the neat explosive nor in the "sugar" mocks.

Shown in Figs. 5 and 6 are comparison plots of the stress-strain behavior of the four materials

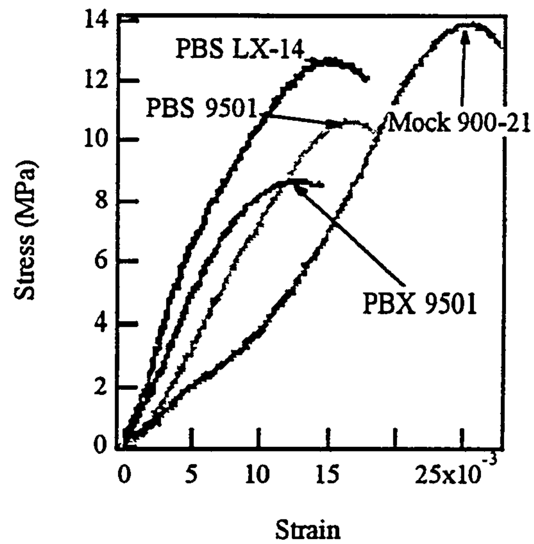

FIGURE 5. A comparison plot of the stress-strain behavior of the four materials studied at 25 C and a strain rate of 1.11e-3 s^{-1}.

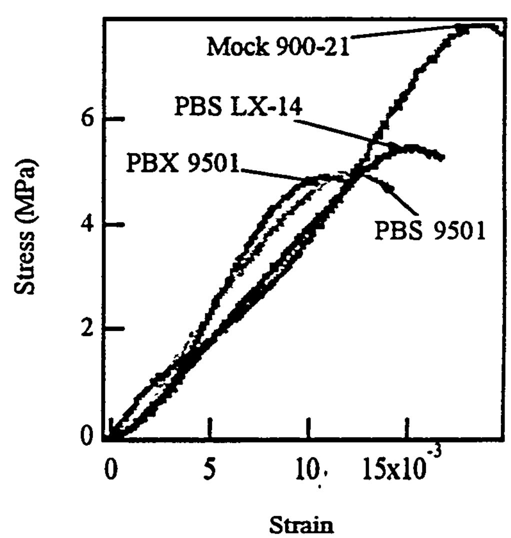

FIGURE 6. A comparison plot of the stress-strain behavior of the four materials studied at 25 C and a strain rate of 1.11e-3 s^{-1}.

studied at a strain rate of 1.11e-3 s^{-1} and at 25 and 60 C respectively. As seen in the figures, the 900-21 strength and density mock least resembles the behavior of the neat 9501 at both temperatures. The PBS 9501, however, most resembles the PBX 9501 at both temperatures, and the agreement is better at higher temperatures. This is perhaps not surprising, since the sugar mocks were prepared so as to match the behavior of the neat 9501 or LX-14 explosive as closely as possible.

DISCUSSION

As stated previously, little work has been done on many of the PBX's in use today. Hoge studied the strain rate effects in PBX's (9404) using standard compression and the split-Hopkinson bar technique.[2] More recently, Peeters has characterized PBX 9501, PBX 9502, and mock 900-10 at strain rates from 1.6 e-5 to 1.6 e-3 in both compression and tension geometries.[3] Browning et al., using these and creep data, have characterized PBX 9502's material properties leading to the development of an integral formulation of a visco-plastic model for describing the behavior of 9502.[4,5] Schapery, in work conducted for the Navy, studied composite propellants and the work subsequently led to a visco-elastic - plastic constitutive model that also included damage.[6] Field and his coworkers have examined the material properties of PBX's, primarily at low rate, and have determined some of the failure mechanisms for the PBX's.[7]

The PBX's are members of the class of compounds that exhibit visco-elastic behavior. They are not perfectly visco-elastic, however, as stressing the samples can cause permanent damage through plastic-grain debonding (or dewetting), crystal fracture, or plastic work. In fact, these damage processes are what give rise to the enhanced sensitivity of PBX's following an impact. The data above show (1) the unconfined compressive weakness of the explosive materials, (none of the materials exceeded 20 MPa at the strain rates studied), and (2) that a composite consisting of sugar embedded in a volumetric mix of plastic binder can approximately simulate the material response of the real explosive. We did observe that the PBS 9501 was slightly stronger than the PBX 9501 at every strain rate and temperature studied. There are (at least) two possibilities for these discrepancies. As stated previously, C&H sugar matches the particle size distribution of the coarse HMX used in 9501. 9501 is composed of both a fine grain and a coarse grain mix of the explosive. Our PBS 9501, however, was composed of only the coarse sugar; confectioners sugar makes a good fine grain, and perhaps the use of only coarse grain causes the increase in compressive strength due to greater coarse grain to coarse grain contact. The other possibility arises from the fact that estane exhibits time-dependent behavior; the chain length of the polymer decreases with time and this has been correlated with a decrease in the compressive strength of PBX 9501.[8] The lot of 9501 we are using in our study was made in 1989, and our sugar formulations were generated over the past year. Thus, it may be that the change in compressive strength is due to the decreased chain length of the estane in PBX 9501. We are in the process of generating aged PBS 9501 (the estane is artificially aged through heating) to test our hypothesis. Additionally, we intend to generate mocks with the correct grain size distribution using both coarse and fine grain sugar.

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