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# LOW STRAIN RATE COMPRESSION MEASUREMENTS OF PBX 9501, PBXN-9, AND MOCK 9501

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Low strain rate ($10^{-3}$ to $10^{-1}$ 1/s) compression measurements have been obtained on three different composite materials: PBX 9501, PBXN-9, and a sugar mock of PBX 9501. These measurements expand on earlier efforts to identify the behavior of PBX 9501 and sugar mocks at different rates, aspect ratios (L/d) and temperatures. PBX 9501 samples at three different L/d's were strained at the same rate to evaluate L/d effects on the stress-strain parameters. Extensometer and strain gage data obtained with these measurements were also compared for precision. PBXN-9 data were obtained at two different L/ds, two different temperatures, and at three different rates. The PBXN-9 data exhibit similar trends to other energetic materials data, i.e. 1) increased ultimate compressive strength and modulus of elasticity with either an increase in strain rate, or decrease in temperature, and 2) small changes in the strain at maximum stress with changes in temperature or strain rate. A comparison of the PBXN-9 data to the PBX 9501 data shows that both begin to fail at comparable strains, however the PBXN-9 data is considerably weaker in terms of the ultimate compressive strength.

## INTRODUCTION

Quasi-static compression data at room and low (-55° C) temperatures, were obtained on PBXN-9 samples with two different aspect (L/d) ratios, and at three different rates each. Measurements were also obtained on PBX 9501 samples with three different aspect ratios compressed at the same strain rate to identify possible end effects on the stress-strain parameters and the failure modes of the samples. New 9501 sugar mock samples, formulated with a bimodal distribution of coarse and fine grain sugar similar to the HMX grain distribution in PBX 9501, were tested to identify stress-strain parameter differences between the bimodal and singular coarse grain formulation sugar mocks. Steve Sheffield, et. al.[1], have previously shown with particle size distribution measurements and light microscope images that coarse and fine grain sugars have similar particle size distributions to measurements made on coarse[2] and fine lots of HMX respectively.

## EXPERIMENTAL

Low strain rate compression measurements were obtained with an Instron 1123 Materials Testing Workstation for PBXN-9 (92/2/6 wt % HMX/HyTemp 4054/dioctyl adipate), PBX 9501 (95/2.5/2.5 wt% HMX/Estane/BDNPA-F), and 9501 sugar mock (94/3.0/3.0 wt% C&H sugar/Estane/BDNPA-F) samples. Compression samples were machined from pressed billets of the individual composite materials. Load and strain measurements were obtained with an Instron load cell and extensometer. The nominal sample diameters (d), lengths (L), temperatures, and strain rates of the different composite tests are given in Table 1.

## DATA ANALYSIS AND RESULTS

The raw data is converted to true stress-strain format. An offset accounts for discrepancies in the machine/sample compliance that occurs just before the surfaces completely mate and uniaxial compression is achieved. The adjusted stress-strain curve is then evaluated for the elastic modulus, $E$, which is defined as the slope of the linear regression fit, the maximum stress or the ultimate compressive strength, $\sigma_m$, and strain at maximum stress, $\varepsilon_m$.

Figure 1 is an example of the calculated, averaged, true stress-strain data obtained on PBXN-9 samples with an aspect ratio (L/d) of 2 at room and cold temperatures and three different strain rates. An examination of the data shows: 1)all three stress-strain parameters, $E$, $\sigma_m$, and $\varepsilon_m$, increase with a temperature decrease, 2)both $\sigma_m$ and $E$ show a greater dependence on the strain rate than $\varepsilon_m$ at the lower temperatures, whereas 3) $\varepsilon_m$ shows more dependence on the strain rate than the other two values at room temperatures.

**TABLE 1**: Test parameters for the new PBXN-9, PBX-9501, and 9501 sugar mock tests

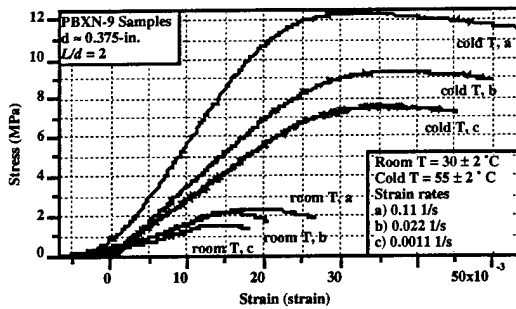| Sample | Nominal Diameter ≡ d (inches) | Nominal Length ≡ L (inches) | Average Test Temperature | Nominal Strain Rate (1/s) |
|---|---|---|---|---|
| PBXN-9 | 0.375 ± 0.003 | 0.5625 ± 0.003 | 30 ± 2 °C, and -55 ± 2 °C | 0.0015, 0.030, and 0.15 |
| PBXN-9 | 0.375 ± 0.003 | 0.750 ± 0.003 | 30 ± 2 °C, and -55 ± 2 °C | 0.0011, 0.022, and 0.11 |
| PBX 9501 | 0.375 ± 0.002 | 0.375 ± 0.001 | 23.4 ± 2 °C | 0.0022 |
| PBX 9501 | 0.375 ± 0.002 | 0.750 ± 0.001 | 26.5 ± 2 °C | 0.0022 |
| PBX 9501 | 0.375 ± 0.002 | 1.500 ± 0.003 | 27.7 ± 2 °C | 0.0022 |
| 9501 Sugar Mock | 0.375 ± 0.005 | 0.750 ± 0.001 | 15.2 ± 2 °C | 0.0011 |



**FIGURE 1.** Calculated true stress-strain data for PBXN-9 samples at room and cold temperatures at 3 different strain rates. Sample diameters were nominally 0.375-in. with $L/d = 2$.

The PBXN-9 compressive mechanical property trends are similar to those previously seen with previous compression results on composite materials.[4-8] A comparison of the PBXN-9 true stress-strain data with four of these materials, a)mock 900-21, b)LX14 coarse grain sugar mock, c)9501 coarse grain sugar mock, and d)PBX 9501, obtained at a strain rate of 0.0011 1/s at room temperatures with samples of the same diameter and aspect ratio are shown in Figure 2.
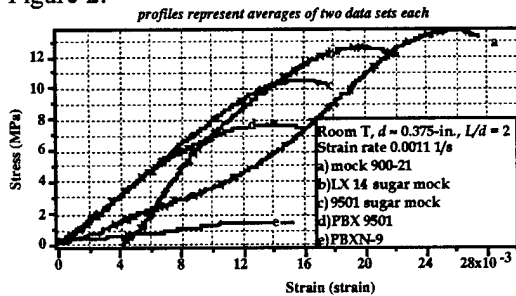


**FIGURE 2.** Calculated true stress-strain data from averaged data of a) mock 900-21, b) LX14 sugar mock, c) 9501 sugar mock, d) PBX 9501, and e) PBXN-9.

An evaluation of these data readily show: 1)the PBX 9501 displays considerably more ultimate compressive strength than the PBXN-9 composite materials with comparable maximum strains, 2)the 9501 coarse grain sugar mock is comparable to PBX 9501 in terms of the elastic modulus and maximum strain, but the sugar mock shows higher compressive strength, and 3)both the LX14 sugar mock and mock 900-21 show more compressive strength and considerable different elastic moduli and maximum strains than the other three materials.

The differences between the PBX 9501 and PBXN-9 compressive strengths were expected based on visual and tactile comparison of the pristine samples and prior knowledge of the composition of the formulations. The PBXN-9 more readily deforms under finger pressure, and has a more putty-like feel than the PBX 9501. Also, in comparison to PBX 9501 the PBXN-9 has 1) less of the hard phase component, HMX, and a higher weight percentage of the binder soft phase mixture, 2) a different elastomer, HyTemp 4054 , with a polybutyl acrylate backbone similar to unvulcanized gum rubber, and 3) a higher weight percentage of plasticizer, dioctyl adipate, present in the binder mixture. In contrast to PBXN-9, the 2.5/2.5 wt% Estane/BDNPA-F in the PBX 9501 binder system would exhibit higher strength properties due to block co-polymer properties of Estane, and the presence of less plasticizer.

The response of the PBXN-9 material to compression at cold temperatures, -55 ± 2 °C, was somewhat unexpected. The glass transition temperature of PBXN-9 has been reported as -43 °C[9], similar to the -40 ± 5 °C for PBX 9501. Two feasibility tests were first performed with 9501 sugar mock at ≈ -55 °C, and at the slowest strain rate. Both tests produced brittle shear failure in the samples exhibiting the classical 45° fracture to the cylindrical axis of the sample. On the other hand, all of the PBXN-9 tests performed at cold temperatures produced samples that responded with more ductile behavior.

Additional compression data were obtained on three different aspect ratios of PBX 9501,

$L/d = 1$, 2, and 4, with nominal diameters of $0.375 \pm 0.002$-in (see Table 1), at the same strain rate and room temperatures to evaluate possible $L/d$ effects on the stress-strain behavior and parameters . It is known[10] from previous work on various materials ranging from solids, e.g. metals, to composites, e.g. concrete, that mechanical properties measurements can be affected by $L/d$ effects. Large L/ds display failure dominated by buckling effects due to unparallel ends and machine misalignment. The smaller L/ds show failure dominated by frictional end effects, but these can be mitigated by lubrication. Lubrication techniques and the possible effects on the stress-strain parameters were also recently investigated by Liu, and Stout using 9501 sugar mock samples.[11] Their analysis indicates that lubrication type only modifies the toe region data of the true stress-strain curve, and that the true stress-strain parameters remain unaffected by the lubrication type. Therefore lubrication was used for the compression measurements on PBX 9501.

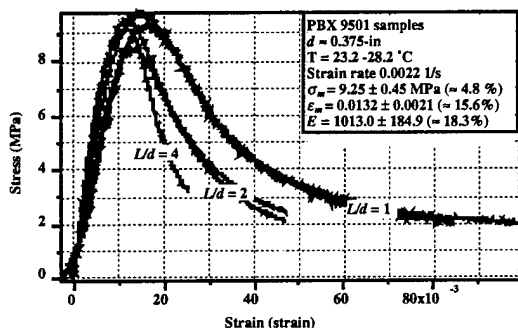. Figure 3 shows the calculated true stress-strain data cfrom the six PBX 9501 measurements.



**FIGURE 3.** True stress-strain data for PBX 9501 samples at three different aspect ratios, L/d =1, 2, and 4. Measurements were obtained at room temperatures with a strain rate of 0.0022 1/s.

A comparison of the data shows that all six measurements have nominally the same $\sigma_m$, $\varepsilon_m$, and $E$ values within 18.3% or less, with the highest precision on the ultimate compressive strength. The most notably difference occurs in the stress-strain data after the ultimate compressive strength has been reached. A visual analysis of the PBX 9501 samples provides some evidence for these differences. The largest $L/d$ samples exhibited buckling at one of the two sample ends, whereas the smallest L/d samples only exhibited barreling near center and some macrocracking through the length of the sample. Based on these measurements, and those obtained by Liu and Stout[11], the stress-

strain curve behavior after the ultimate compressive strength is reached is indicative of the failure mode behavior for that particular aspect ratio.

The new bimodal, 9501 sugar mock sample data were obtained to evaluate possible mechanical property differences between the bimodal and coarse grain sugar mock samples. A total of nine measurements (see Table 1) were obtained at a strain rate of 0.011 1/s, at room temperatures, and without lubrication. Figure 4 shows the true stress-strain data calculated from these measurements.
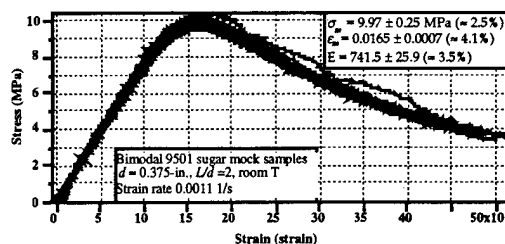


**FIGURE 4.** True stress-strain data for 9501 sugar mock samples with a bimodal 3:1 coarse to fine grain distribution of sugar. Data were obtained at a rate of 0.0011 1/s and at room temperatures, using samples with a nominal diameter of 0.375-in. and L/d =2.

With the exception of one measurement, all of the data shows amazing consistency and precision in the $\sigma_m$, $\varepsilon_m$, and $E$ values. Eight out of the nine measurements were averaged for comparison with the coarse grain sugar mock sample data obtained previously. These data are shown in Figure 5.



**FIGURE 5.** Averaged true stress-strain data for coarse grain and bimodal grain samples of 9501 sugar mock. Measurements were made at room temperatures with a strain rate of 0.0011 1/s with samples of nominal diameter 0.375-in., and L/d =2.

A comparison of their $\sigma_m$, $\varepsilon_m$, and $E$ values, given in Table 2, shows that all three stress-strain parameters are essentially the same within 10% or less, regardless of the difference in sugar grain distribution.

**TABLE 2**: Averaged true stress-strain parameter values for both 9501 sugar mock samples. An experimental error of 10% was assumed to determined the range on each value.

| Sample | $\sigma_m$ (MPa) | $\varepsilon_m$ | $E$ (MPa) |
|---|---|---|---|
| 9501 coarse grain sugar mock | $10.5 \pm 1.1$ | $0.016 \pm 0.0016$ | $783 \pm 78$ |
| 9501 bimodal grain sugar mock | $9.85 \pm 0.99$ | $0.016 \pm 0.0016$ | $737 \pm 74$ |

## SUMMARY

Low strain rate compression measurements on PBXN-9 at room and cold temperatures display similar composite material trends seen with other energetic and mock materials. These trends include the dependence of the stress-strain parameters, $\sigma_m$, $\varepsilon_m$, and $E$, on strain rate and test temperature, i.e. as either the strain rate increases or the temperature decreases the stress-strain parameters tend to increase in value. A comparison of the data previously obtained on PBX 9501 with the more recent PBXN-9 measurements shows that the PBXN-9 is more ductile in its behavior with lower overall ultimate compressive strengths and elastic moduli. This behavior was expected based on the previous evaluation of formulation differences and visible material properties. The PBXN-9 measurements coupled with the PBX 9501 measurements clearly indicate the dependence of the stress-strain parameters on the formulation properties of the composite.

A comparison of the stress-strain parameters obtained from different aspect ratios of PBX 9501 shows that the parameters are not affected greatly by the $L/d$ differences within 18.3% or less. Nonetheless the failure behavior of the stress-strain data are indicative of $L/d$ failure mode and cracking/fracture behavior differences in the samples.

A comparison of the stress-strain parameters for both the bimodal and coarse grain 9501 sugar mock samples shows comparable values for all 3 evaluated stress-strain parameters within 10% or less.

## REFERENCES

1. S. A. Sheffield, R. L. Gustavsen, R. R. Alcon, and J. G. Archuleta, LANL DX-1 and DX-2, private communication, December 1996.
2. J. Dick, Combustion and Flame, **54**, 121 (1983).
3. 1996 Annual Book of Standards, Section 8 Plastics, Volume 08.01 Plastics (I) D 256-D 2343, ASTM Standard D 695-91, p. 87 (1996).
4. D. J. Funk, G. W. Laabs, P. D. Pederson, and B. W Asay, "Measurement of the Stress/Strain Response of Energetic Materials as a Function of Strain Rate and Temperature: PBX 9501 and Mock 9501," Proceedings of the APS Topical Conference on Shock Compression of Condensed Matter, Seattle, WA, p. 145, 1995.
5. D. A. Wiegand, Proceedings of the 3rd International Conference on Deformation and Fracture of Composites, University of Surrey, Guildford, U.K., p. 558, 1995.
6. D. A. Wiegand and J. J. Pinto, Material Research Society Symposium Proceedings, Vol. 909, "Fracture Instabilities, Dynamics, Scaling, and Ductile/Brittle Behavior," p. 281 (1996).
7. D. A. Wiegand, Proceedings of the Army Science Conference, Norfolk, VA, June 1996.
8. D. A. Wiegand, "Influence of Added Graphite on the Mechanical Strength of Pressed Plastic Bonded Explosives," U.S. Armu Armament Research, Development and Engineering Center Technical Report ARAED-TR-95018, January 1996.
9. B. Baudler, NSWC Technical Report, 86-334, August 1989.
10. N. E. Dowling, Mechanical Behavior of Materials: Engineering Methods for Deformation, Fracture, and Fatigue, Prentice-Hall Inc., Upper Saddle River, NJ, p. 174, 1993.
11. Cheng Liu and M. Stout, LANL MST-5, private communication, October and November 1996.

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