LA-UR 99-3248

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Author(s): W.R. Blumenthal, G.T. Gray III, D.J. Idar, M.D. Holmes, P.D. Scott, C.M. Cady, and D.D. Cannon

Mail Stop G-755, Los Alamos National Laboratory
Los Alamos, NM 87545

Presented at: 1999 APS Topical Conference on Shock Compression in Condensed Matter (APS SCCM 99)

27 June - 2 July 1999
Snowbird, UT

Published in : *Shock Compression of Condensed Matter - 1999*, edited by M.D. Furnish, L.C. Chhabildas and R.S. Hixson, American Institute of Physics Conference Proceeding 505, Melville, New York, 2000, pp. 671-674.

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INFLUENCE OF TEMPERATURE AND STRAIN RATE ON THE MECHANICAL BEHAVIOR OF PBX 9502 AND KEL-F 800™

W.R. Blumenthal, G.T. Gray III, D.J. Idar, M.D. Holmes, P.D. Scott, C.M. Cady, and D.D. Cannon

Mail Stop G-755, Los Alamos National Laboratory, Los Alamos, NM 87545

Abstract. Compression measurements were conducted on plastic-bonded explosive PBX 9502 and its binder, Kel-F 800™, as a function of temperature from -55˚C to +55˚C using an improved split Hopkinson pressure bar at high strain rates ($\approx$ 1400 s^{-1}) and at low strain rates ($\approx$ 0.001 to 0.1 s^{-1}) at ambient temperatures. PBX 9502 exhibits lower dynamic compressive strength, but is much less sensitive to strain rate and temperature, than PBX 9501. In contrast, the mechanical response of the Kel-F 800™ binder is stronger than pure (or plasticized) Estane™, but is again less strain rate and temperature dependent. The effects of longitudinal and transverse loading orientations (due to preferred orientation of TATB) and virgin versus recycled TATB on the properties of PBX 9502 are presented.

INTRODUCTION

Understanding and modeling the mechanical response of polymers and polymer-based composites is of great interest for defense and commercial applications, particularly the stress-strain response of plastic-bonded high explosive (PBX) composites and aging effects that may occur in the polymer binder. New continuum models, based on actual physical and chemical mechanisms, must account for complex phenomenology including temperature, strain rate, orientation, and aging effects on mechanical performance if a predictive capability is to be achieved.

Conventional methods have been used to measure the mechanical properties of polymers and PBX composites at low strain rates. However high strain rate methods using the split Hopkinson pressure bar (SHPB) must be modified for these materials to achieve stress equilibrium with low sound speed materials; to obtain adequate pressure bar signal output at very low stress levels; and to minimize undesirable stress triaxiality caused by friction on specimen interfaces. Recent studies by the authors (1) have shown how to minimize these issues by optimizing specimen geometry, through the use of low modulus pressure bars, and by using lubricants effective over a wide range of temperatures.

The constitutive responses of a number of polymers and polymer-bonded high explosives have been studied as a function of strain rate and temperature as reviewed previously (2-4). In general, the compressive strength and the loading modulus of polymeric materials increases with decreasing temperature and increasing strain rate. PBXs tested at high and low strain rates both show a distinct maximum in their flow stresses (compressive strength) at low strains (1-5%) followed by a decline in the stress with continued deformation. However, the rate and duration of this decrease is dependent on the specimen geometry, material, strain rate, and the temperature and corresponds to a complex process of micro-to-macrostructural damage accumulation (1).

In the present investigation, uniaxial compression tests were performed at quasi-static and high-strain rates from -55˚C to +55˚C on PBX 9502 and its binder, Kel-F 800™. Virgin and recycled PBX 9502 were evaluated for mechanical anisotropy in two principal orientations (longitudinal and transverse to the direction of densification). These results are compared to data for PBX 9501 and pure Estane™.

EXPERIMENTAL TECHNIQUES

Materials and Preparation

PBX 9502 is composed of 95 wt% triamino-trinitrobenzene (TATB) and 5 wt% Kel-F 800™ binder. TATB (T_{melt} ~448°C) is a triclinic crystal with a micaceous, plate-like morphology that is susceptible to preferential orientation (texturing) during processing. Specifically, the plate normals are aligned perpendicular to the direction of an applied shear stress or parallel to compressive loading. The dimensions of the TATB crystals are on the order of 10-50 microns in diameter and sub-micron to 10 microns in thickness. The glass transition temperature (T_g) is slightly less than the T_g of Kel-F 800™ indicating little interaction between the binder and the TATB (5).

Kel-F 800™ is an amorphous, 3:1 copolymer of chlorotrifluoroethylene and vinylidene fluoride with a T_g of ~28°C, a melting temperature of ~105°C, and an ambient specific gravity of 2.0 g/cm^3 (5). Kel-F 800™ was vacuum compression molded at 93°C and a pressure of 6 MPa into a plate with a diameter 200mm by 12mm thickness to approx. full density.

Three lots of PBX 9502 were tested in this study: two virgin lots (890-019 and 890-022) and one recycled lot (891-005) made with a 50% fraction of reclaimed TATB (3). Quasi-static compression specimens, 25.4mm diameter by 25.4mm long, were machined with a compression axis parallel to the billet pressing direction (longitudinal). Specimen densities ranged between 1.886 to 1.893 g/cm^3. Compression specimens for SHPB testing were machined from both PBX-9502 and Kel-F 800™ with dimensions of 6.35mm diameter and 3.2mm length which has been shown to be an effective geometry for achieving the stress-state equilibrium required for valid SHPB testing of slow sound speed polymers and PBXs (1,2). SHPB compression specimens of PBX 9502 were machined in two principal orientations: parallel (longitudinal) and perpendicular (transverse) to the billet pressing direction. These orientations were chosen to maximize the anisotropic effect of preferential texturing of the TATB crystals. Quasi-static compression specimens of Kel-F 800™ were machined with 6.35mm diameter and 6.35mm length in the plate through-thickness direction only.

Due to the soft, visco-elastic nature of Kel-F 800™ at ambient temperatures, a special liquid nitrogen cooling procedure was employed to machine specimens with parallel loading surfaces (2).

Low Strain Rate Compression Testing

Ambient temperature quasi-static compression tests on PBX 9502 were conducted with Instron 5567 and 1123 test machines and extensometer gauges (Canton, MA) at strain rates of 0.08 and 0.0008 s^{-1}. Quasi-static tests on Kel-F 800™ were conducted from -55°C to +24°C using a MTS (Eden Prairie, MN) model 880 load frame and ram extensometer at a strain rate of 0.001 s^{-1}. PBX 9502 specimens were loaded to failure (<10% strain) and Kel-F 800™ specimens were loaded to a strain of ~30% before unloading. Specimens were lubricated with molybdenum disulfide and tested in laboratory air with a relative humidity of ~15±4%

High Strain Rate Compression Testing

Dynamic tests were conducted on both PBX 9502 and Kel-F 800™ at a strain rate of ~2000 s^{-1} utilizing a modified split-Hopkinson pressure bar (2). This system uses 9.4mm diameter Ti-6Al-4V alloy pressure bars to improve the signal-to-noise output associated with low strength polymers.

Test temperatures of -55°C to +55°C were achieved during testing using a helium gas heating/cooling system described earlier (1). Specimens were ramped to the desired temperature in approximately 5 minutes and equilibrated at temperature for approximately 10 minutes prior to testing. SHPB samples were lubricated with a thin spray coating of boron nitride and a thin layer of molybdenum disulfide grease.

RESULTS AND DISCUSSION

PBX 9502

Selected longitudinal compression curves are plotted in Fig. 1 for the 50% recycled PBX 9502 lot. These data show a moderate dependence on both strain rate and temperature for PBX 9502. Specifically, the strength at 20°C increases by a factor of 1.6 from 27 MPa at 0.001 s^{-1} to 44 MPa at 1400 s^{-1}. However, this is far less than the factor of 7 increase in compressive strength exhibited by PBX 9501 under similar strain rate conditions (1). PBX 9501 is much stronger at high strain rates and much weaker at low strain rates compared to PBX 9502. Figure 1 also shows that the flow stress peaks for PBX 9502 consistently between 1.5% and 2.5% strain before slowly decaying with further strain. However, the decay in flow stress becomes very rapid at -40°C (and below) indicating a rapid loss of toughness under dynamic loading.

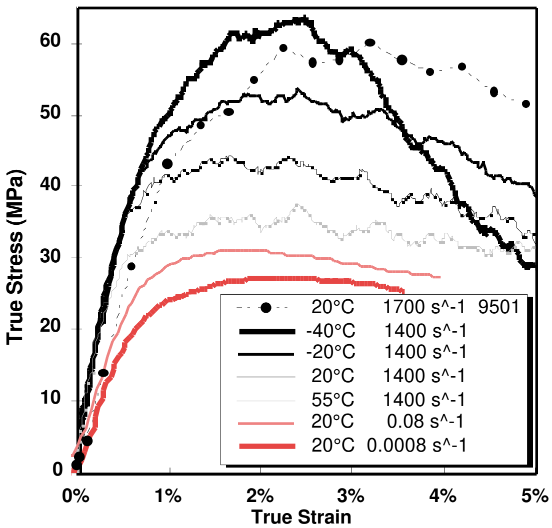

FIGURE 1. Longitudinal compression behavior of 50% recycled PBX 9502 as a function of strain rate and temperature. PBX 9501 is shown at 20°C for comparison.

Figure 2 is a summary plot of PBX 9502 strength (peak stress) versus test temperature for the entire spectrum of materials and conditions studied. A comparison of virgin and recycled PBX 9502 lots shows that the recycled PBX 9502 is approximately 15% stronger than the virgin lots independent of strain rate, temperature, and loading orientation. The compressive strength of the two virgin lots of PBX 9502, indicated by two data points, were virtually identical for all temperatures and strain rates, confirming a high degree of reproducibility for the same nominal material.

The effect of loading orientation on the strength is seen to vary with temperature for both the virgin and recycled lots. At temperatures above 20°C the transverse orientation is 10-15% stronger than the longitudinal. However, below -20°C the longitudinal strength is equal to or stronger than the transverse orientation. Finally, a polynomial fitted to the virgin PBX 9502 data in Fig. 2 shows that the strength reaches a maximum with temperature between -40°C to -60°C. This corresponds to the drop in toughness indicated by the post-peak stress-strain curve in Fig. 1. The flattening strength behavior above +50°C corresponds to a 20-30°C shift in the glass transition temperature associated with high-strain-rate loading.

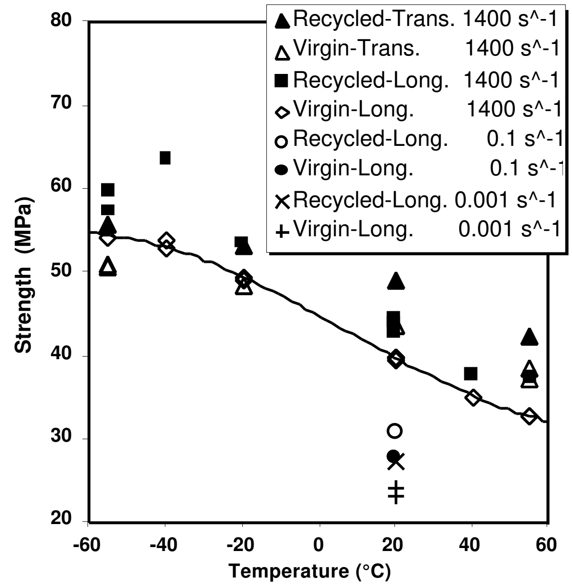

FIGURE 2. Temperature dependence of the compression strength of virgin and 50% recycled PBX 9502 as a function of strain rate and loading orientation.

Kel-F 800™ Binder

The compressive stress-strain response of Kel-F 800™ is shown in Fig. 3 for several strain rates and temperatures along with several curves for pure Estane™. A peak in the flow stress is often observed at approximately 10% strain. Similar to the comparison of PBX 9501 and PBX 9502, Kel-F 800™ is much less strain rate and temperature dependent than pure (or plasticized) Estane™. However, Kel-F 800™ is much stronger than pure Estane™.

Figure 4 is a plot of flow stress (at 10% strain) versus temperature for Kel-F 800™ that demonstrates linear temperature dependencies at both high and low strain rates. High strain rate loading increases the temperature dependence (slope) of the flow stress and shifts the line to higher stress (or, equivalently, to higher temperatures).

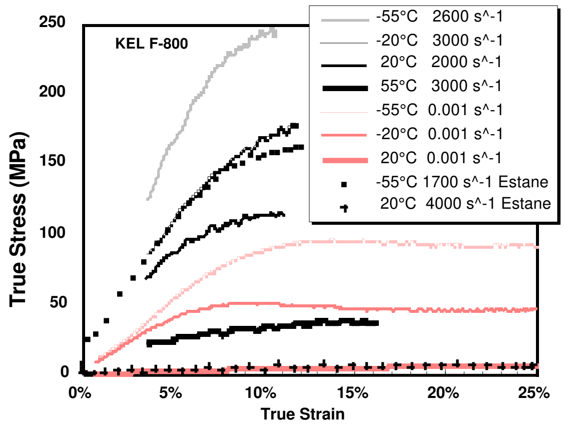

FIGURE 3. Compressive behavior of pure Kel-F 800™ at several temperatures and strain rates. Estane™ is shown for comparison.

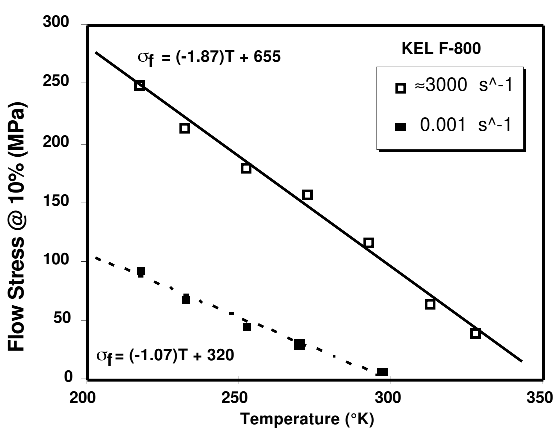

FIGURE 4. Flow stress (@ 10% strain) versus temperature of Kel-F 800™ at several strain rates.

Note that the quasi-static x-axis intercept of 299°K corresponds closely to the measured glass-transition temperature of Kel-F 800™ of 301°K and that the x-axis intercept at high strain rates (350°K) is approaching the melting temperature of Kel-F 800™ (378°K) (5).

SUMMARY AND CONCLUSIONS

The following conclusions can be drawn: 1) the compressive stress-strain response of PBX 9502 and its binder system, Kel-F 800™, are moderately dependent on both strain rate and temperature, but not as strongly as PBX 9501 and Estane™; 2) PBX 9502 containing 50% recycled material is measurably stronger (~15%) than virgin formulations; and 3) a small anisotropy in the compressive strength of PBX 9502 (recycled and virgin) has been observed, presumably due to preferential alignment of the TATB crystals during densification.

ACKNOWLEDGMENTS

The authors wish to greatly thank Collin Sadler for preparing the Kel-F 800 material. This work was performed at the Los Alamos National Laboratory under the auspices of the U.S. Department of Energy (contract W-7405-ENG-36).

REFERENCES

1. Gray III, G. T., Blumenthal, W. R., Idar, D. J. and Cady, C. M., "Influence of Temperature on the High-Strain-Rate Mechanical Behavior of PBX 9501," in *Shock Compression of Condensed Matter-1997*, edited by S.C. Schmidt et al., AIP Conference Proceeding 429, New York, 1998, pp. 583-586.
2. Gray III, G.T., Idar, D. J., Blumenthal, W.R., Cady, C.M., and Peterson, P. D., "High and low-strain rate compression properties of several energetic material composites as a function of strain rate and temperature" in *Proc 11th Symposium (Int.) on Detonation*, held 31 August-4 September 1998, Snowmass Village, CO, in press.
3. Idar, D. J., Rabie, R. L., and Scott, P. D., "Quasi-Static, Low-Strain Rate Compression Measurements of Thermally Treated and Mechanically Insulted PBX 9502 Samples," Los Alamos National Laboratory report LA-UR-97-5116 (1997).
4. Idar, D.J. and Holmes, M.D. "Quasi-static, Low Strain Rate Compression Measurements of PBX 9502 and Mock 900-24 Specimens," Los Alamos National Laboratory report LA-UR-98-5270 (1998).
5. Campbell, M.S., Garcia, D.A., Idar, D.J., "Effects of Temperature and Pressure on the Glass Transitions of Plastic Bonded Explosives", Los Alamos National Laboratory report LA-UR-98-3971 (1998).