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SURFACE TEMPERATURE MEASUREMENTS OF HETEROGENEOUS EXPLOSIVES BY IR EMISSION

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We present measurements of the integrated IR emission (1-5 μm) from both the heterogeneous explosive PBX 9501 and pure HMX at calibrated temperatures from 30°C to 250°C. The IR power emitted as a function of temperature is that expected of a black body, attenuated by a unique temperature independent constant which we report as the thermal emissivity. We have utilized this calibration of IR emission in measurements of the surface temperature from PBX 9501 subject to 1 GPa, two dimensional impact, and spontaneous ignition in unconfined cookoff. We demonstrate that the measurement of IR emission in this spectral region provides a temperature probe of sufficient sensitivity to resolve the thermal response from the solid explosive throughout the range of weak mechanical perturbation, prolonged heating to ignition, and combustion.

INTRODUCTION

It has long been recognized that solid phase temperature is a key observable for understanding the behavior of energetic materials. Experiments designed to measure temperatures associated with shock initiation in plastic bonded explosives have included both fast thermocouple (1) and IR radiometric (2) techniques.

Current problems of interest in these explosives, including the violence of reaction after prolonged heating and the thermal response when subject to mechanical deformation, require the development of techniques to measure surface temperature which allow both high sensitivity and high spatial and temporal resolution. We have recently demonstrated the ability to obtain IR emission from the surface of unconfined explosives subject to weak impact (3).

In this report we present quantitative measurements of the integrated IR emission (1-5 μm) from both the heterogeneous explosive PBX 9501, and the pure components at calibrated temperatures from 30°C to 250°C. The IR power emitted as a function of temperature from these materials is that expected of a black body, attenuated by a unique temperature independent constant we report as the thermal emissivity. We also report preliminary measurements of surface temperature, based on this calibration, in both mechanical and thermal ignition experiments spanning a temperature range of 30 °C to 400°C and microsecond to millisecond timescales.

EXPERIMENTS AND RESULTS

We apply IR Radiometric techniques based on InSb (Indium Antimonide) detection to determine the surface temperature from measurements of IR radiant power (4). Determination of surface temperature from radiant power over a frequency

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interval ν_i to ν_f is accomplished via the Plank black-body distribution

$$dP = \frac{4\pi h}{c^2}\frac{A_d}{2}\varepsilon \sin^2(\theta)\int_{\nu_i}^{\nu_f}\frac{\nu^3\eta(\nu)\,\sigma(\nu)\,d\nu}{\exp(h\nu/kT)-1} \qquad (1)$$

where P is the radiant power, θ is the acceptance half angle, A_d the surface area element, ε the temperature independent emissivity, T the temperature, ν the frequency, and h, c and k the usual fundamental constants. The frequency distribution is convoluted with the detector quantum efficiency, $\eta(\nu)$, and responsivity, $\sigma(\nu)$. We apply a single lens imaging geometry in which the surface area element from the sample is equal to the known detection element area and θ is determined by the focal distance and the lens radius. The convolution functions $\eta(\nu)$ and $\sigma(\nu)$ for InSb semiconductor materials are well known. The radiant power as a function of temperature is thus a function of the single unknown constant, the emissivity ε.

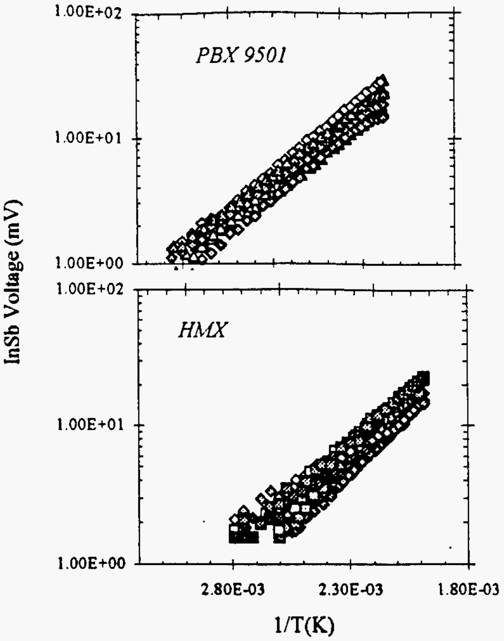

FIGURE 1. Detector voltage as a function of inverse temperature in Kelvin for PBX 9501 and pure HMX. Both samples were pressed. The data are from several different samples of each material.

Calibration Experiments

We have calibrated the detectors used in this work by imaging the surfaces of both MIKRON and Electro-Optics standard black-body ovens. We used the single lens geometry described previously. Assuming unit emissivity from the standard surface, the measured voltage as a function of temperature directly yields the detector responsivity upon numerical integration of Eq. (1).

The measurements of surface emissivity from the various explosive components were then performed in an analogous manner. Explosives and component materials were held at known temperatures and the InSb detector voltage measured to generate a curve of voltage as a function of temperature. These curves have been plotted for several independent measurements of PBX 9501 and pure HMX surfaces in Fig. (1). Plotted as the logarithm of voltage against $1/T$ a black-body response is linear with a constant slope, $h\nu/k$, independent of material and with an intercept which is a temperature independent function of the emissivity, ε. This is the observed shape in $\log(V)$ vs. $1/T$ for the samples of Fig. (1) and all other materials reported here. The varying intercept in these data reflect a variable emissivity from the surfaces of different samples of the same material. This variance is considerably larger than the statistical uncertainty in the individual determination of ε from a single curve and reflects an inherent, morphological variation. This will directly affect the accuracy of the inversion of voltage data to generate surface temperatures. The measured emissivity from a number of components of PBX 9501 are summarized in Table 1. We have

Table 1. Summary of measured emissivity from components of PBX 9501 from 50 to 200°C.

Sample material		**emissivity, ε**	**σ**
PBX 9501	(pressed)	0.75	0.14
HMX	(pressed)	0.64	0.14
Estane	(polyurathane rubber)	0.25	0.09
Binder[a]		0.73	0.09

[a] The binder is a 50/50 blend of Estane and bis dinitropropyl acetal/formal.

utilized this calibrated radiometric system in two preliminary dynamic experiments.

Mechanical Impact

We first present the measured temporal and spatial temperature field from the surface of a PBX 9501 sample during deformation resulting from a 1 GPa impact. The details of the experiment, including measurement and calculation of the surface displacement field as a function of time during deformation, are described in companion papers in this symposium (5,6). Briefly, a rectangular sample of PBX 9501 (25 mm x 10 mm x 5 mm) is confined in a steel assembly at the end of a light gas gun. One inch diameter sapphire windows confine the large area sides of the sample. The sample is subject to impact by a brass bullet (190 m/s) impinging on a rounded steel plunger of 19 mm radius which couples the weak shock into the narrow end of the sample. The two dimensional weak shock propagates through the sample, and the spatial and temporal profiles of the resulting temperature field are recorded from the surface through the IR transparent windows.

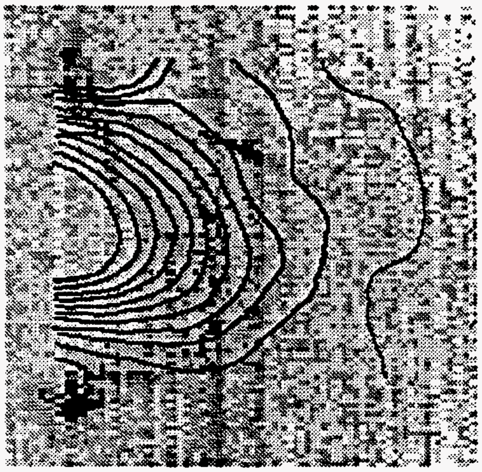

FIGURE 2. Imaged surface of PBX9501 subject to 1 GPa impact on the left side by a rounded plunger (19 mm radius). Darker regions indicate higher temperatures.

The spatial profile of the surface temperature ~100 μs after impact is shown in Fig. 2. The detector, from Santa Barbara Inc., consists of 40 μm elements in a 256x300 array. The darker regions indicate higher temperatures, and reflect the symmetry of the plunger from the rounded impact surface at left, tapering to cold material ~1 cm ahead. The surface temperature varies from ~50°C in the heated region to sharp temperature increases near ~100°C at the boundaries. Superimposed on this image is the displacement vector field, which clearly demonstrates the correlation between particle motion, boundaries and heating.

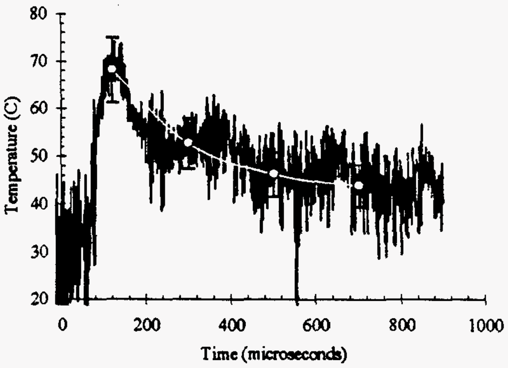

FIGURE 3. Surface temperature recorded subsequent to 1GPa impact (Time=0). The error bars correspond to uncertainty in calculated temperature due to emissivity uncertainties reported in Table 1.

The temporal profile of the temperature field over approximately a millisecond is shown in Fig. 3. This detector, from Cincinnati Electronics, consists of two parallel linear arrays of eight 80 μm elements, with 10 μs risetime amplification. The error bars reflect the uncertainty in temperature which results from the uncertainty in surface emissivity reported in Table 1.

Unconfined Cookoff

We have also conducted preliminary experiments to measure the surface temperature of PBX 9501 during spontaneous thermal ignition. In these experiments the Cincinnati Electronics detector was utilized with 1 μs rise time electronics. The samples were right circular cylinders with both length and diameter of 1 cm. The samples, which were placed in an open oven and heated over approximately three hours, appeared unchanged to external observation until the temperature reached approximately 235°C, when ignition occurred and the sample completely decomposed in approximately a second. The IR signal from the surface was measured, with single lens imaging as above, both during the heating trajectory and during the first 40 ms of rapid decomposition. The ignition data for one experiment, showing the signal from eight detectors imaging different areas of the surface, are shown in Fig. (4).

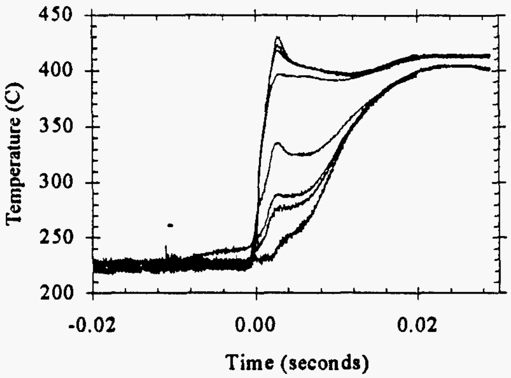

FIGURE 4. Temperature recorded from eight adjacent surface elements 80x80μm. Recorded from unconfined PBX 9501 during ignition subsequent to prolonged heating.

The data exhibit several reproducible features. These include the small 'pre-ignition' rise in temperature from the surface prior to t=0 and the rapid temperature rise defined as ignition. The temperature rises to a constant from some areas of the surface quickly, with much slower rise to the same constant temperature from other areas of the surface.

CONCLUSIONS

The calibration experiments, ranging from ambient through critical temperatures of PBX 9501, indicate a reliable measurement methodology for these materials.

The powerful physical description enabled by such detailed temperature measurement is clear from the preliminary results reported here. The spatial and temporal temperature fields of Figs. (2) and (3), and the correlation of these fields with both the impact symmetry expected of the rounded plunger and the measured surface displacement (5) will place a considerable constraint on the mechanism of heating in prospective constitutive models. Data such as the detailed temporal behavior of the surface temperature during ignition in the unconfined cookoff experiment are revealing many of the physical and chemical mechanisms involved in coupling thermal decomposition with ignition and even combustion.

These experimental examples, and many other problems of current interest concerning explosive safety illuminate the need for precise measurement of the thermal fields generated by a number of coupled thermal and mechanical perturbations. These examples represent the beginning of a program to obtain such measurements in our laboratory.

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REFERENCES

1. Bloomquist, D. D. and Sheffield S. A., Thermocouple Temperature Measurements in Shock Initiated PBX-9404, *Seventh Symposium on Detonation*, Annapolis, MD, 1004-1009, 1981.
2. Von Holle, W. G. and Tarver, C. M., Temperature Measurements of Shocked Explosives by Time Resolved Infrared Radiometry - A New Technique to Measure Shock-Induced Reaction, *Seventh Symposium on Detonation*, Annapolis, MD, 993-1003, 1981.
3. Asay, B. W., D. J. Funk, G. W. Laabs, and P. J. Howe. *Measurement of Strain and Temperature Fields During Dynamic Shear of Explosives*. in *Shock Compression of Condensed Matter, American Physical Society Topical Conference*. 1995. Seattle, WA.: AIP Press.
4. McCluney, *R., Introduction to Radiometry and Photometry*, Artech House, Boston, 1994.
5. B. W Asay, B. F. Henson, P. M. Dickson,C. S. Fugard, and D. J. Funk. *Direct Measurement of Strain Field Evolution During Dynamic Deformation of an Energetic Material*. in *Shock Compression of Condensed Matter*. 1997. Amherst MA: AIP Press.
6. K. S. Haberman, J. G. Bennett, B. W. Asay, B. F. Henson and D. J. Funk. *Modeling, Simulation and Experimental Verification of Constitutive Models for Energetic Materials*. in *Shock Compression of Condensed Matter*. 1997. Amherst MA: AIP Press.

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