INSTRUMENTATION OF SLOW COOK-OFF EVENTS

H. W. Sandusky and G. P. Chambers

Energetic Materials Research and Technology Department
NAVSEA Indian Head Division, 101 Strauss Ave., Indian Head MD 20640-5035

Abstract. An arrangement was developed for validating models of slow cook-off. Experiments were conducted on the explosive PBXN-109 with measurements of temperature, pressure, and volume until the onset of reaction; and measurements of case velocity and blast overpressure during reaction. The goal is to relate changes in the energetic material during heating with time and position for onset of reaction plus reaction violence as a function of sample size, confinement, gas sealing, and heating profile. A mild range of reactions occurred as evidenced by fragmentation of the confinement into mostly large pieces; however, at the highest confinement no sample was recovered.

INTRODUCTION

Cook-off is both complex and quite dependent on a variety of environmental factors, such as the rate of heating, which is fast in a fuel fire and orders of magnitude slower from indirect heating. In addition to heating rate, the variables include sample size (diameter and length-to-diameter ratio), radial and axial confinement, initial ullage, and sealing of pyrolysis products during heating. Since only a limited number of full-scale tests can be conducted, which limits the number of variations in environmental factors, it would be advantageous to predict cook-off response to different hazard scenarios with computer models. Models at the Sandia National Laboratory, Albuquerque (SNLA) (1,2) and the Lawrence Livermore National Laboratory (3) were evaluated against small-scale screening tests, such as the Variable Confinement Cook-off Test (VCCT). It was recognized that model validation requires better controls on the tests and more measurements in each test. In addition, the properties of heated explosives are being characterized (4,5) to support the modeling effort.

Suitable metrics for comparing models and experiments include the rate of expansion of the energetic material, temperature at various locations within the energetic material and at various points on and in the apparatus, strain in the confinement and pressure buildup within the confinement as a function of time, evolution of gaseous decomposition products, time at which cook-off occurs, and the violence of that reaction. In some experiments, it would be advantageous to stop the heating at some point in the cycle and remove the explosive for evaluation of thermal damage and decomposition. To meet these requirements, an experimental arrangement was developed that is different than the usual closed pipe in most small-scale cook-off tests. An initial series of experiments was conducted on the explosive PBXN-109, which is RDX and aluminum in a rubber binder. A companion program (6) with a closed pipe is being conducted at the Naval Air Warfare Center/China Lake (NAWC/CL).
EXPERIMENTAL ARRANGEMENT

The apparatus shown in Figure 1 consists of a test cell mounted between flat springs in a load frame, which is simply two pieces of 152 mm wide steel channel connected by 25 mm threaded rods. Between each spring and base there can be a spring stop in which is mounted a potentiometer-based displacement transducer. Spring displacement has also been measured by a strain gage mounted on the spring, which is calibrated by replacing the explosive samples with hydraulic oil and pressurizing the test cell. There is a clear field of view around the test cell for measurements of rapid expansion and fragmentation of the confinement with flash radiography and high-speed photography. The other measurement of reaction violence is blast overpressure by a transducer within a meter of the apparatus.

Details of the test cell are shown in Figure 2. A cylindrical sample of the same dimensions as that in the VCCT, 25.4 mm diameter by 63.5 mm long, is radially confined in a seamless mechanical tube of 1018 steel with variable thickness and axially with spring-loaded rams. Confinement is dependent on the thickness of the tube and the strength of the springs. The springs reduce the internal pressure buildup – expansion from heating and damage in the sample and pyrolysis products – so that the seals on the rams are not breached. The rams have axial ports for instrumentation within the samples, which to date have been thermocouples sealed by epoxy. Each ram also has an O-ring seal with the confinement tube. The tube is heated by resistance wire with minimal insulation so that the field of view is not obscured. The rams are somewhat thermally isolated from the springs to reduce the heat loss from the ends of the sample and thereby maintain more uniform temperatures over the sample length.
TABLE 1. Summary of PBXN-109 Cook-off Experiments

<table>
<thead>
<tr>
<th>Tube Wall Thickness (mm)</th>
<th>Heating Profile, Start &amp; Ramp</th>
<th>Ullage (%)</th>
<th>Gradient (°C/25 mm)</th>
<th>Cook-off Temp. (°C)</th>
<th>% Explosive Recovered</th>
<th>No. of Tube Fragments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.27</td>
<td>130 °C, then 6 °C/hr</td>
<td>-3.6</td>
<td>18</td>
<td>172</td>
<td>35</td>
<td>4</td>
</tr>
<tr>
<td>1.90</td>
<td>150 °C, then 3 °C/hr</td>
<td>-3.6</td>
<td>11</td>
<td>170</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>2.54</td>
<td>150 °C, then 3 °C/hr</td>
<td>-1.0</td>
<td>11</td>
<td>165</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>

The displacement of the springs was measured either by a potentiometer-based displacement transducer, as shown in Figure 1, or with a strain gage on each spring calibrated for displacement. For both techniques, spring displacement was related to pressure on the rams by hydraulically pressurizing the tube before each experiment. Temperatures on the confinement and within the sample were measured by copper-constantan thermocouples from 0.25-mm diameter wire with Teflon insulation. The tube typically had a strain gage at the midplane and a break-wire, both circumferentially mounted. During heating, tube strain is a second measure of interior pressure, calibrated by hydraulically pressurizing the tube. If a high-elongation strain gage of annealed constantan is used, this gage can also follow the initial tube expansion during the onset of cook-off. Along with the break-wire, the strain gage also serves as trigger probe for the dynamic diagnostics during cook-off. The apparatus and the associated instrumentation were evaluated experimentally and computationally (7) with inert samples of Teflon.

The PBXN-109 is from the same batch as that used in the NAWC/CL tests. (6) The sample, with a total mass of ~52 g, is in three pieces with 1-mm diameter holes drilled for the thermocouples.

RESULTS AND DISCUSSION

The conditions and results from three experiments are summarized in Table 1. The major input condition varied was the wall thickness of the confinement tube. Heating profiles replicated those at NAWC/CL (6). The relatively high starting temperatures prior to the slow heating permitted completion of each experiment in 8 hrs. The 3.6% ullage in the first two experiments was from the sample being 0.33 mm smaller in diameter than the tube and slightly oversized holes for thermocouples. The 1% ullage in the last experiment was achieved by eliminating the clearance between the sample and tube.

With the ~3.6% ullage, there was no significant spring deflection from thermal expansion; however, during the three hours prior to cook-off there was an exponential increase from thermal damage and pyrolysis. This is illustrated in Figure 3 for the second experiment, where the spring deflection at cook-off corresponds to 1.9% increase in sample length and a 2.7 kpsi (18.7 Mpa) sample pressure. With the minimal ullage in the last experiment, thermal expansion was recorded as shown in Figure 4; however, the confinement leaked at 4 kpsi. The last pressure drop was probably from seepage around a thermocouple whose signal was lost.

Heat losses through the rams caused the thermal gradients listed in Table 1 between the midplane thermocouples and the one 25.4 mm from the midplane. The gradient is significant in that the levels of thermal damage and self-heating...
in the samples are reduced near the rams. Internal temperatures near cook-off are shown in Figure 5 for the second experiment, with the thermocouple locations shown in Figure 2. Despite the uniformity of temperature for the two midplane locations up to one hour before cook-off, self-heating only appeared on the axis. At 12.7 mm below the midplane where temperatures are 6 °C lower, no self-heating appeared even on the axis.

The amount of explosive recovered decreased with increasing tube wall thickness. The explosive recovered in the second experiment was only millimeter size pieces, indicating an axial reaction that fractured the surrounding annulus once the confinement failed. In the experiment with the thickest wall, an overpressure of 12.6 psi was measured 0.60 m away; there were several small tube fragments; and at a circumferential wall strain of 8%, the wall velocity was 42 m/s. Perhaps this was an explosion, whereas the reactions in the previous experiments were deflagrations.

SUMMARY AND CONCLUSIONS

Simultaneous mechanical and thermal measurements were made during slow cook-off of an explosive designed to be insensitive to various hazardous stimuli. Cook-off violence for PBXN-109 was similar to that observed in other small- and full-scale tests. There is significant pressure from thermal expansion when ullage is essentially eliminated, but only expansion without a pressure increase for several percent of ullage. At a heating rate of 3 °C/hr, self-heating occurs on the axis in a small, <10 mm zone.

ACKNOWLEDGEMENTS

This program was promoted by a number of individuals, most notably Art Ratzel at SNLA, Alice Atwood at NAWC/CL, and Ruth Doherty at this Center. Ken Schebella when visiting this Center from DSTO in Australia, Kevin Gibson, Richard Lee, and Vasant Joshi assisted various aspects of the experimental development. The Office of Naval Research provided funding.

REFERENCES