Research Article

High-Speed Study of Drop-Weight Impact Ignition of PBX 9501 Using Infrared Thermography

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Reaction in explosive materials does not occur as a result of homogenous heating of the sample, but rather from a localized region of high temperature called a hot spot. Observation of hot spot development is critical in understanding the heat transfer mechanisms occurring during reaction. Due to the strong temperature dependence of explosives, the overall reaction rate is dominated physically by these hot spots. Once formed, these hot spots either fail to react chemically due to thermal diffusion or react exothermically thus creating an ignition site in the solid explosive. The slightest difference of physical properties can change the positioning of hot spot development, creating an argument that the differences in material properties influence the formation of hot spots, which produce an exothermic reaction.

Reaction in explosive materials does not occur as a result of homogenous heating of the sample, but rather from a localized region of high temperature called a hot spot [1–7]. Observation of hot spot development is critical in understanding the heat transfer mechanisms occurring during reaction. Due to the strong temperature dependence of explosives, the overall reaction rate is dominated physically by these hot spots [8–10]. Once formed, these hot spots either fail to react chemically due to thermal diffusion or react exothermically thus creating an ignition site in the solid explosive. The slightest difference of physical properties can change the positioning of hot spot development, creating an argument that the differences in material properties influence the formation of hot spots, which produce an exothermic reaction [10].

Bowden et al. [2–7] suggests that the critical size for ignition of a hot spot is around $10\ \mu\text{m}$ in diameter with temperatures in excess of 500°C . PBX 9501 has a bimodal crystal size distribution centered at 25 and $130\ \mu\text{m}$ [4]. Bowden and Gurton [3] also showed through earlier experiments that the kinetic energy available in a drop-weight impact tester is only capable of raising the temperature of the material

by a few degrees. So, it is apparent that some other form of localized energy development is necessary to lead to hot spot formation and ignition. Bouma et al. [11] explains that particle size distribution is an important property in influencing both sensitivity to mechanical deformation and reactivity of the material.

The impact sensitivity PBX 9501 was investigated using a modified type 12 impact tester (Figure 1, Key Kinetics, Inc.) in conjunction with a FLIR SC6000 thermal imaging camera and R-tools data acquisition software. High-speed infrared imaging is a novel method for studying the impact ignition of explosives. The impact tester has a drop mass of 1 kg with an intermediate mass of 1.5 kg. Each test was conducted with $30 \pm 5\ \text{mg}$ pressed sample placed on the anvil. The intermediate mass is rested on the specimen, and the drop mass makes contact with the top of the intermediate mass (Figure 1).

The drop mass is released from a variable height, and the infrared camera is used to determine ignition based on a go/no-go determination. Once an optimal range is found in which there are positive and negative reactions, tests are conducted on 1 cm intervals. Using an abbreviated Bruceton method, the lowest drop height that produces a greater than

FIGURE 1: Experimental setup.

FIGURE 2: High-speed infrared image of impact.

50% reaction is used to calculate ignition energy through potential energy. The infrared camera is used to determine the velocity of the drop mass as it travels to the sample. The high-speed capabilities of the SC6000 (4000 fps) are also an effective tool to measure the time between initial contact and ignition of the sample.

Impact sensitivity was also examined as a result of thermal insult or indirect heating. Two different sets of samples were tested: undamaged or pristine samples and damaged samples of PBX 9501. The material was damaged by indirect exposure in a volumetric combustion oven at 250°C for 1 hour. The exposure is considered indirect because the samples were enclosed in another container inside of the oven so that the material was not directly exposed to the heat source.

Frictional heating is identified and widely accepted as a cause of ignition in the drop-weight system due to the interaction and plastic deformation of the spherical particles [8–20]. Photographic data during the drop-weight impact testing shows the sample compresses and then fragments

[20] (Figure 2). Previous research [8–15, 21] shows that when this happens, small gas spaces become trapped and ignition occurs because of the collapse of this gas space. Adiabatic shear bands are clearly forming in and around the sintered region (Figures 3 and 4). The ignition site (Figure 4) develops in the vicinity of the shear bands and the reaction appears to spread radially along the shear bands. The reaction continues to propagate and consume the entire sample.

Table 1 shows the ignition energies measured with the drop weight apparatus at high fire, low fire, and Bruceton method. High-fire conditions require a 90% positive reaction while low-fire conditions require a 10% positive reaction. The Bruceton method was also used and is based on a 50% positive reaction.

It is important to note that all of the damaged samples of PBX 9501 reacted below the low fire conditions for undamaged PBX 9501. In other words, *the damaged material reacts 100% of the time at the same height that undamaged material reacts 10% of the time.*

FIGURE 3: Photographic sequence of impact.

FIGURE 4: (a) Thermogram of PBX 9501 during impact (the white region is at 341°C and the dark outer regions are at $23^{\circ}\text{C} \pm 0.8$), (b) Simultaneous photographic image.

TABLE 1: Ignition energies from impact testing of undamaged PBX 9501.

PBX 9501	High (m)	Low (m)	50% (m)	High (J)	Low (J)	50%(J)
Sample 1	0.20	0.13	0.13	1.96	1.28	1.28
Sample 2	0.13	0.06	0.09	1.28	0.59	0.88
Sample 3	0.12	0.10	0.11	1.18	0.98	1.08
Sample 4	0.10	0.07	0.08	0.98	0.69	0.78
Sample 5	0.10	0.06	0.08	0.98	0.59	0.78
Sample 6	0.09	0.07	0.08	0.88	0.69	0.78
Sample 7	0.13	0.07	0.08	1.28	0.69	0.78
Sample 8	0.13	0.10	0.12	1.28	0.98	1.18
Average	0.13	0.08	0.10	1.23	0.81	0.94
St. Dev.	0.034	0.025	0.021			

Several hot spot mechanisms are operating during the drop-weight studies on PBX 9501. The frictional heating between the particles of explosive material and both the anvils and each other helped initially to raise the temperature of the sample. Thermograms of the reactions show adiabatic shear banding which creates localized energy of the system and creates hot spots as well as trapped gas that becomes compressed during impact. The size of the gas pocket is dependent on the grain size of the sample.

The results clearly show that PBX 9501 becomes more sensitive to mechanical impact after exposure to indirect heating. *The results show that for indirect exposure at 250°C for 1 hour, the impact ignition threshold of PBX 9501 for high-fire conditions drops at least 80%.* This is a very important safety consideration both for storage and machining of this explosive material.

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