Radiant Ignition Models for Nitramine Propellants

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Recent efforts to reduce ignition sensitivity and improve gun performance by replacing the entire ignition train with lasers (i.e., direct ignition) can be helped by reliable radiant ignition models.. For interior ballisticians a prime requirement for these models is the ability to predict initial pressurization rates in gun chambers.

Phenomenological radiant ignition models use global kinetics for condensed phase energy production rates of energetic materials[1].These models can predict ignition delays but not pressurization rates. Model validation is usually made by comparing emission ("first light") delay measurements with calculated ignition delays[2]. The usual ignition criterion is a sharp increase in temperature at or near the surface. The origin of the emission is not usually considered. Recent physical radiant ignition (and combustion) models for nitramine propellants consider detailed chemical kinetic mechanisms for condensed and gas phases[3]. These models can, in principle, predict temporal variations in chemical species, temperature and pressure. Validation of these models can be made by comparing predictions with measurements of emission delays, pressurization (delays and rates) and transient appearances (and concentrations) of gaseous products.

Radiant ignition models (1-D) for solid propellant usually assume uniform and steady flux densities at the surface. The effects of gaseous products from laser ablation/pyrolysis on radiation transmission to the surface are not consider. Including these processes in models may affect predictions.

This paper will present recent results of an investigation of CO2 laser ignition of pressed pellet samples of neat RDX (cyclotrimethylene trinitramine) and samples cut from extruded strands of XM39, a heterogeneous gun propellant containing approximately 75% RDX in an inert binder (cellulose acetate butyrate).

Experiments were conducted in a windowed chamber at atmospheric pressure in air and N2 with radiant flux densities = 10 - 200 cal/cm2-s and pulse length < 2s. The experimental techniques have been described previously[4] . Transient pressure was measured with a piezoelectric transducer. Photomultipliers (λ = 300-800 nm response) were used to record wave-length integrated emission from the plume generated near the surface of the samples. Simultaneous records of emission from excited OH and CN species were obtained using interference filters (λ = 310 and 388 nm, respectively). Identification of species produced during ignition was made from emission spectra (λ = 250 - 850 nm) using a CCD/spectrometer (Princeton Instruments; .1 nm. resolution). The

spectra were integrated over various time intervals during (laser assisted flame) and after (unassisted flame) the laser pulse. The effects of XM39 (in air) ablation products on laser transmittance to the sample surface was determined by measuring transmission through holes (.029" diameter) in ¼"O.D x ½"cylinders. Comparison with Delran (inert polymer with thermophysical properties similar to solid propellants) and brass were made to help interpret the results.

Experimental results:

The initial results from analysis of RDX and XM39 emission spectra indicate that CN, NH, OH and CH are some of the molecular species generated in laser assisted and self-propagating flames (Na and K are also present). Except for greater intensity during the laser pulse, the spectra from "laser assisted" and self-propagating flames appear similar. There seems to be little difference in spectra obtained in N2 or air. Except for greater intensity the RDX spectrum appears similar to XM39. There are many features in the spectra which, as yet, have not been identified.

Species and temperature profiles obtained previously from PLIF investigations[5] of CO2 laser assisted deflagration of RDX are consistent with predictions of a detailed chemical kinetic mechanism for nitramine combustion[6]. Measurements (flux densities~150cal/cm2-s) in N2 and air at 1atm indicate little effect of O2 on results. This is consistent with the absence of an O2 effect on the emission spectra. Measurements of pressure delays at lower flux densities with and XM39[7] and RDX[8] in N2 air at 1atm show little effect of O2 on the delays themselves but a large effect on initial pressurization rates[7] . This seems to be inconsistent with the absence of an O2 effect on the PLIF and emission spectra for RDX.. Emission spectra will be obtained using a higher resolution) and the results of further efforts to identify additional species will be presented.

The flux density used to determine the effect of gaseous products on transmittance was kept sufficiently low (laser duty cycle<50%) so that gasification/pyrolysis occurred only with Delran and XM39 while the brass surface was unaffected during exposure. At exposure times of 0.1s and 0.3s the presence of gaseous products results in transmission decreases of about 20 and 40 % with Delran and 45 and 70 % with XM39. Transmission was constant with brass. This suggests that surface temperature calculations for CO2 laser radiation ignition models need to account for these transmission losses.

A comparison of the flux dependence of ignition delay predicted by a phenomenological ("adiabatic") model with times to observe emission (first light) and pressurization have been presented previously for XM39[7] and RDX[8] . The calculations used global kinetics derived from DSC experiments and reflection and absorption coefficients determined from reflection and transmittance measurements for XM39. Agreement is good at high flux values where delays are short and relatively independent of kinetics. At low flux values agreement with the magnitude of predicted delays is less satisfactory but the predictions of the fall-off in delays as flux increases are in good agreement with measurements.

Comparisons of the experimental results with predictions of recent physical radiant ignition models (1-D) will be made.

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