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Optical spectroscopy to study confined and semi-closed explosions of homogeneous and composite charges

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Confined and semi-closed explosions of new class of energetic composites as well as TNT and RDX charges were investigated using optical spectroscopy. These composites are considered as thermobarics when used in layered charges or enhanced blast explosives when pressed. Two methods to estimate fireball temperature histories of both homogeneous and metallized explosives from the spectroscopic data are also presented, compared and analyzed. Fireball temperature results of the charges detonated in a small explosion chamber under air and argon atmospheres, and detonated in a semi-closed bunker are presented and compared with theoretical ones calculated by a thermochemical code. Important conclusions about the fireball temperatures and the physical and chemical phenomena occurring after the detonation of homogeneous explosives and composite formulations are deduced.

1. Introduction

Thermobaric explosives (TBXs) and enhanced blast explosives (EBXs) are volumetric weapons of first choice to use in enclosed and semi-closed spaces. Detonation of such materials is accompanied by an important energy release and a great thermal effect [1]. Great efforts are made for understanding the fundamental physical and chemical phenomena occurring during the detonation and explosion of such formulations. To date, a variety of techniques have been developed to measure pressure in detonations and fireballs. However; experimental determination of fireball temperature, when and where the metallic additives burn using direct in situ measurements of explosive fireballs is difficult because of the short time scales and the extreme environments of high temperatures and pressures. Therefore, using non-intrusive optical techniques to observe radiant emissions from the fireball is a possible alternative. Optical techniques can also provide knowledge of which gaseous or condensed species appear in the fireball; therefore, chemical signatures from explosives can be detected by examining their emission spectra [2,3].

At high temperature the heat transferred by radiation is predominant. The emissivity is a function of temperature and wavelength and quantifies how well a substance radiates energy in form of light. It is a value to specify how well a real body radiates energy in comparison with a black body at the same temperature [4]. Unfortunately, to date, emissivity data during the rapid explosion phenomena cannot be properly estimated and approximations have been used for temperature calculations.

Optical pyrometry uses continuous spectra emitted by the reaction products to determine temperature. Temperature is estimated from the Wien relation using the measured intensities (radiance) at two different wavelengths under the assumption that the emissivity is a weak function of wavelength (gray-body approximation) [5–8]. However; if the explosives are metalized, like in the case of thermobaric explosives, metallic particles undergo heterogeneous combustion, strong absorption lines superimposed on the continuous spectrum may appear. Moreover, sodium and less frequently potassium emission lines were also observed from emission spectra recorded from fireballs of homogeneous high explosives (trinitrotoluene – TNT, nitromethane – NM) [5,9–11]. Consequently, erroneous results and conclusions may be derived if one (or more) of the pyrometer working wavelengths coincides with such emission or absorption lines. Data collected from emission spectroscopy records of the fireballs can be used to assist in the choice of the working wavelengths of the pyrometer.

Emission spectroscopy data could directly be used to estimate temperature of the explosive fireball. However, evidences exist that the explosion fireball is an optically dense media, hence, the data collected by the spectrometer represent the intensity emitted by species and gases only in or near the surface of the fireball. J. M. Peuker et al. studied the attenuation of 532 nm light by fireballs

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from aluminized high explosives using photometric and imaging methods [12,13]. The absorbance was found to peak during the early period of high reactivity of post detonation gases, but a significant decrease in the optical depth beginning after 160 µs was observed. Moreover, it is important to notice that if this absorbance or attenuation is similar for both wavelengths chosen for temperature estimation by the pyrometric method, this does not affect the calculated temperature. It was also proven experimentally that attenuation does not affect temperature results calculated from spectroscopic data if it is similar for the entire range of wavelength taken into calculation. In another work, L.S Lebel et al. [14] developed a fiber optic that can obtain spectroscopic measurements inside the explosive fireball at different distances from the explosive charge. It was found that time and magnitude behavior of temperature was not significantly different when taken at different location within the fireball which means that temperature inside the fireball is uniform. The same method (emission spectroscopy) was also used by the author of publication [15]. Emission spectra were collected from the detonation of 20 g aluminized RDX (cyclo-1,3,5-trimethylene-2,4,6-trinitramine) charge using fiber optics located behind the flame front (at distances less 10 cm or 30 cm from the charge) and then compared with the corresponding spectra from the surface layer collected from the outside of the fireball. Authors found that emission spectra from the surface of the fireball may be regarded as representative of the combustion process in the fireball only after several volume expansions. In the early time of combustion process (for time less than 60 µs), light emission in the interior of the fireball is darker than the exterior, but, once the fuel is well mixed with the surrounding air, no significant differences between temperatures (spectra) estimated from spectra collected from the interior and the exterior of the fireball were found (for time more than 120 µs).

In the present work, optical spectroscopy is used to record spectra radiated from the explosion fireballs of several new thermobaric and classical explosive charges when detonated in confined and semi-confined spaces. The new composite is in a form of pressed pellets or layered charges. A commercial fiber optic was reinforced and is used to take measurements safely. Using the recorded spectroscopic data, fireball temperatures are estimated using two different mathematical methods. One of them showed better precision and reproducibility for all tested charges. Then, the temperature results are presented, discussed and compared to that existing in literature. Thermochemical calculations are also run using CHEETAH code with extended library to verify the experimental results.

2. Experimental approach

2.1. Characteristics of charges

Two kinds, layered and pressed cylindrical charges containing a new composite formulation were used for the investigations. A cross section of the pressed and the layered charge are shown in Figs. 1 and 2, respectively. The composite formulation used for charges elaboration were in form of large complete multi-components energetic macroscopic particles prepared by using the wet method [16]. These granules were spherically shaped and containing RDX, ammonium perchlorate (AP), aluminium (Al) with particle sizes between 44 and 149 µm and Viton. The granules diameter was between 1.1 mm to 1.6 mm. Also, pressed TNT charges and pressed RDXph (RDX phlegmatized with 6% of wax) charges were prepared. Compositions and characteristics of each charge are summarized in Table 1. The composite pressed charges are named hereafter TBX1 and the layered cylindrical one as TBX2. Pressed charges were elaborated using a hydraulic press to obtain pellets. The cylindrical layered charge consisted of a pressed core made of RDXph and an external layer containing the composite. Charges were investigated firstly in a small explosion chamber, weight of each charge was 43 g, the diameter *d* of the pressed

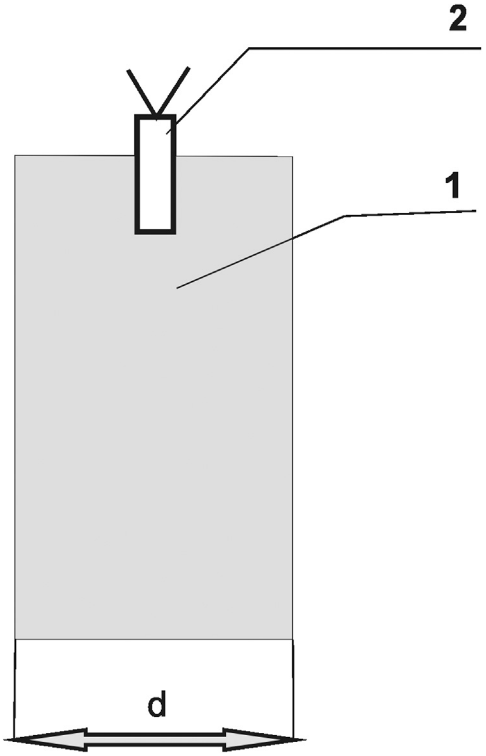

Fig. 1. Schematic of the investigated pressed charge:1 – composite, 2 – detonator.

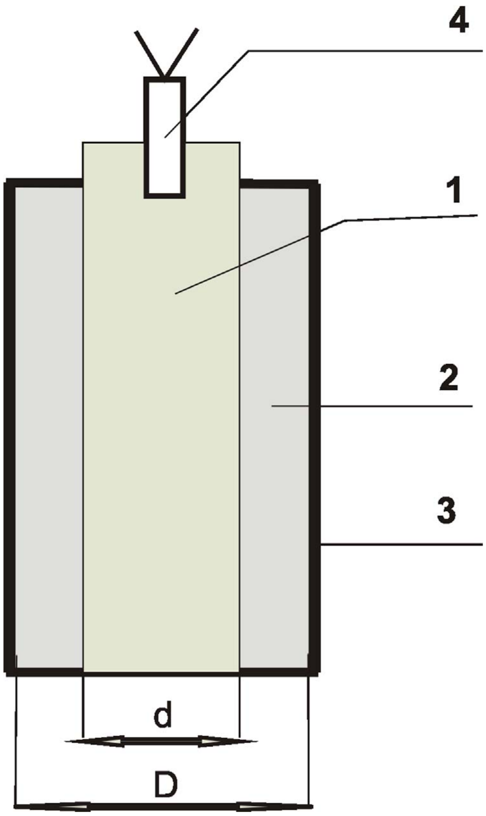

Fig. 2. Schematic of the investigated layered charge: 1 – RDXph core, 2 – composite, 3 – paper tube, 4 – detonator.