



Dynamics of the formation of the condensed phase particles at detonation of high explosives

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Abstract

The article presents the results of the experimental study SAXS on condensed carbon particles that appear at the detonation of a high explosive. It was shown that the SAXS signal rises for 1.5–4 μs after the detonation front passing. The SAXS signal in trotyl and its alloys with hexogen starts just after the compression of the material in the detonation wave. In octogen, hexogen and PETN, the SAXS signal appears in 0.5 μs and is much smaller than the signal at the detonation of trotyl and its alloys with hexogen. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

The synthesis of ultra dispersed diamonds (UDD) at the detonation of condensed explosives with high negative oxygen balance was discovered more than 20 years ago [1,2]. Formation of the solid carbon phase was observed at the very beginning of the study of the detonation processes. However, in spite of the numerous studies of the carbon condensation in the detonation waves, there is no conventional model for this phenomenon. We know neither how the free carbon (not

bonded chemically) leaves the molecules of the parent substance nor the dynamics of the carbon condensation.

The interest in the dynamics of carbon condensation in detonation waves is caused by several reasons. Firstly, it can at least partially clarify the way in which chemical transformations of a substance in detonation waves take place. Secondly, it allows obtaining information on the physics of the nucleus of the condensed carbon phase and their growth.

This work presents the results of the experimental study of the dynamics of the density behavior in the detonation front as well as of the SAXS of the synchrotron radiation (SR) “white beam” on the carbon particles that are formed at

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the detonation of condensed explosives. The experiments were performed at the VEPP-3 storage ring at the Budker Institute of Nuclear Physics SB RAS.

2. Arrangement of the experiments

The experimental stand and basis for the experiment are described in Ref. [3]. The position of the explosive charge relative to the SR beam is shown in Fig. 1. The registration of the SAXS signal and the intensity of the passed SR beam was performed for the detonation waves in pressed charges of trotyl, octogen, hexogen and PETN as well as in alloys of trotyl with hexogen. Charges of powder octogen and pressed charges of hexogen and PETN with admixtures of paraffin and teflon were also studied.

The diameter of the cast charges of the trotyl/hexogen alloy equaled 10 mm and the pressed charges were 12.5 mm in diameter. The length of the charges L was 60 mm.

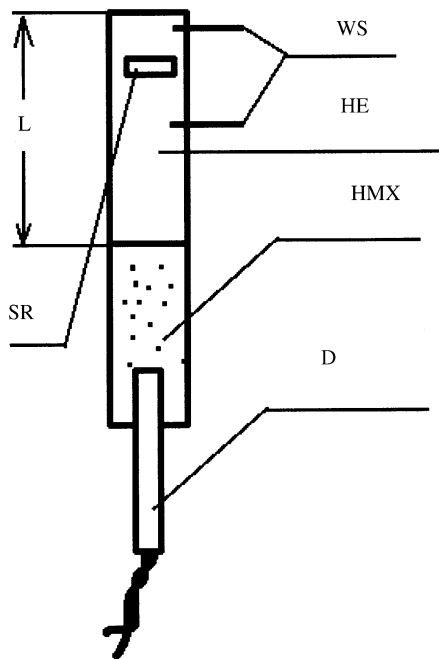


Fig. 1. Scheme of the experiment. SR—synchrotron radiation beam, HE—sample of high explosive, WS—wire sensors, HMX—powder octogen, D—detonator.

The experiments were carried out by several series. Each series consisted of experiments with the 50/50 trotyl/hexogen alloy and results of these experiments were compared with the results of other experiments calibrated (normalized) to a sole current.

3. Results of the experiments

The main experiments were conducted with the detectors from germanium phototransistors (the sensitivity range is 15–30 keV). The results of these experiments are presented by the signals of these detectors. In the cases when it is interesting, the signals of the SAXS detectors from silicon pin-diodes (the sensitivity range is 5–15 keV) will be described.

Fig. 2 presents the signals of intensity of the SR passed beam and SAXS of the germanium and silicon detectors for a charge of the 50/50 trotyl/hexogen.

A sharp fall in the signal of intensity of the SR passed beam corresponds to a compression of the explosive in the detonation wave. The point of the minimal signal lies in the 0.25 μs interval from the signal front. This interval separates the SR flashes in accordance with the period of the electron beam revolution in the storage ring.

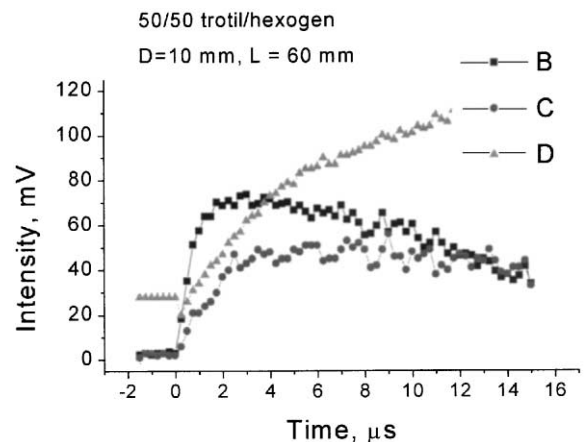


Fig. 2. Sample 50/50 trotyl/hexogen. The intensity of the passed beam (D), SAXS intensity with $E = 5\text{--}15\text{ keV}$ (B) and SAXS intensity with $E = 15\text{--}30\text{ keV}$ (C) versus time.

The average density of the detonation products reaches the initial density of the charge in $0.5\ \mu\text{s}$ because of the dispersion. Later, the intensity of the passed signal keeps rising in accordance with the decrease in density. The character of the variation of the signal of intensity of the SR passed beam is practically the same for all the explosives. The appearance of the SAXS signal at the trotyl/hexogen and trotyl detonation coincides with the point of the maximal recorded density in the detonation wave. The SAXS signal is maximal in the 50/50 trotyl/hexogen; it reaches its highest value in $1.5\text{--}2\ \mu\text{s}$ and falls slowly later on.

For the sake of comparison, Fig. 3 presents the curves of the SAXS signals at the detonation of the charges of trotyl, hexogen and their alloys. At the trotyl detonation, the SAXS signal rises for $3.5\text{--}4\ \mu\text{s}$. The maximal signal value is approximately 1.5 times less than the maximal signal at the 50/50 trotyl/hexogen detonation. The signal fall is slow. In $15\ \mu\text{s}$, the signals' levels become equal and later on, the SAXS signal from the trotyl slightly exceeds the signal from the trotyl/hexogen. The SAXS from pure pressed hexogen exceeds the "background" a little. An addition of 5% of paraffin increases the SAXS signal significantly. The latter becomes only two times smaller than the signal from the 50/50 trotyl/hexogen at a rise time of $4\ \mu\text{s}$. Then, up to $9\ \mu\text{s}$, it stays practically

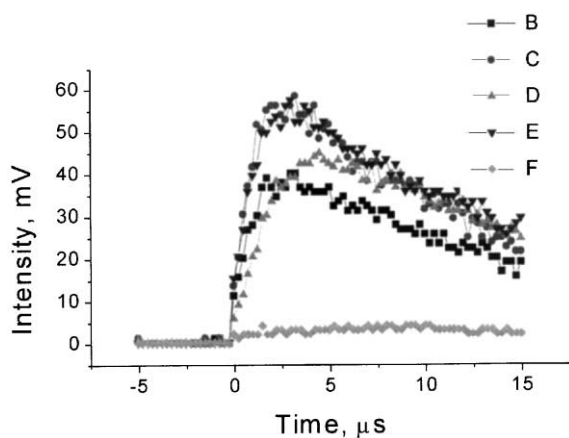


Fig. 3. SAXS intensity for trotyl and hexogen versus time: B—70/30 trotyl/hexogen cast, C—50/50 trotyl/hexogen cast, D—TNT press. $\rho = 1.6\ \text{g}/\text{sm}^3$, E—60/40 trotyl/hexogen cast, F—hexogen press. $\rho = 1.67\ \text{g}/\text{sm}^3$.

constant and after that starts falling slowly. 5% of teflon makes the signal noticeable but it continues to be much lesser than the SAXS signal in the 50/50 trotyl/hexogen.

The same small SAXS signals were obtained at the detonation of the charges of octogen and PETN. Since these signals are very small, they were recorded with large amplification. Fig. 4 presents the results of the experiments for octogen at different densities. Unlike the other explosives, the SAXS signal in the detonation wave falls noticeably and starts rising only in $\approx 0.5\ \mu\text{s}$. In the octogen with a $1.7\ \text{g}/\text{cm}^3$ density, it rises up to the maximal value in $4.5\ \mu\text{s}$. The maximal value of the signals is less than that at the 50/50 trotyl/hexogen detonation almost by an order.

4. Discussion of the results

The authors think that the SAXS signal at the detonation of the explosives studied is determined by the condensed carbon particles. This is verified by the test experiments [3] and by the fact that the SAXS rises when the negative oxygen balance increases for separate explosives. Practically for all the explosives that we studied, the SAXS signal rises, reaches the maximal value and then falls slowly. Such behavior can also be explained by the assumption that all condensed particles are formed in the narrow zone of compression. The relatively

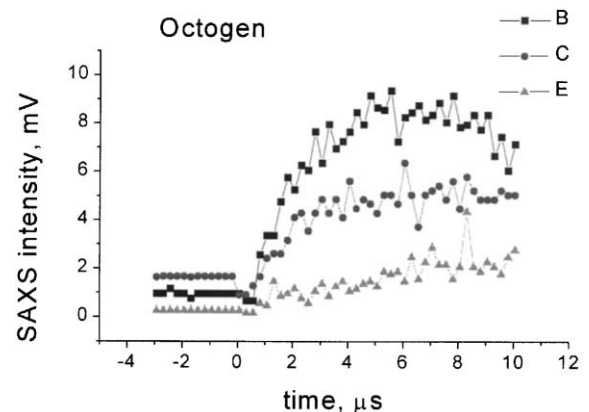


Fig. 4. SAXS intensity for octogen versus time. B—press, $\rho = 1.8\ \text{g}/\text{sm}^3$, C—press, $\rho = 1.64\ \text{g}/\text{sm}^3$, E—powder, $\rho = 1.1\ \text{g}/\text{sm}^3$.

slow rise of the SAXS signal is determined by the increasing contrast of the particles at the dispersion of the detonation products. The SAXS value is formed by $I(\lambda) = \alpha \sum F(\lambda) G(\lambda) (\rho_0 - \rho)^2 N$, where α is the dimension factor, $F(\lambda)$ the shape factor, depending on the crystal structure, $G(\lambda)$ the packing factor, depending on the relative position of the particles, ρ_0 and ρ the densities of the crystals and spreading detonation products, N the number of particles in the path of the X-ray. The total SAXS signal is obtained by summing over all the radiation wavelengths. It is seen from this formula that the SAXS signal depends strongly on the decrease of the density of the detonation products when they spread. The X-ray photos of the spreading of the detonation products were made, and experiments were conducted with flat charges of 50/50 trotyl/hexogen. The SAXS signals measured and those calculated with the assumption that all the crystal particles are formed in the narrow zone beyond the detonation front were compared. The comparison showed that an increase of the “contrast range” at the spread of the detonation products also gives a typical rise and fall of the SAXS signal in 1.5–2 μs . The experimental SAXS signal nevertheless, exceeds the calculated one.

Therefore, we are inclined towards the hypothesis that assumes the growth of the condensed carbon particles not only in the compression zone (where the seed crystals are formed) but also in the spreading detonation products. That is verified indirectly by the experimental results presented in Fig. 3. It follows from the data on the dispersion dynamics that the detonation products of all the charges spread practically equally, i.e. their average densities almost coincide all the time and, therefore, so does the contrast range. Nevertheless, the rate of rising of the SAXS signal from the detonating 50/50 trotyl/hexogen is significantly higher than that from the trotyl charge, even outside the reaction zone. What is the more important, maximums of the signals are shifted by $\approx 2.0 \mu\text{s}$. There is no carbon condensation in the zone of chemical reaction in the octogen, hexogen and PETN; in these explosives, the carbon starts condensing at a distance of more than $\approx 3.0 \text{ mm}$ from the detonation front.

That is witnessed by the electrical conductivity behavior beyond the detonation front in the trotyl [4]. The electrical conductivity rises in a time less than 0.1 μs up to the maximal value and then falls by the exponential law with a typical distance of 1 cm from the detonation front. According to the conductivity model suggested in Ref. [4], the electrical conductivity fall is caused by the dispersion and absorption of the electrons by the condensed particles. The behavior of conductivity in the detonation products of the 50/50 trotyl/hexogen also agrees with our results.

5. Conclusions

The authors understand that the above-described experiments have a qualitative character. Nevertheless, the experiments allowed, for the very first time, getting in the front of the detonation wave and obtaining priceless information and also gave a possibility to demonstrate the SR features for the study of the detonation and shock wave processes. When the experimental technique develops further, SR will permit an investigation of the pressure and temperature distribution in these processes as well as a decoding of the dynamics of the chemical transformation of a substance.

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