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Dynamics of formation of particles of the condensed carbon phase at shock compression of organic materials

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Abstract

Results of the SR study of the density behavior and dynamics of formation of condensed carbon particles at expansion of shock waves in organic materials and some low-sensitive explosives as well as at shock loading of ultra-dispersed diamonds are presented. Appearance of particles of the condensed carbon phase was observed in carbon-rich organic materials.

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1. Introduction

At detonation of many explosives a part of the forming free (not fixed) carbon emerges as condensed particles, in particular as smallest (ultra-dispersed) diamond particles.

Ultra-dispersed diamonds (UDD) were also found to form in the mixtures of high explosives with organic materials (benzol, acetone, paraffin, hexan, ethanol) [1] and graphite. The UDD synthesis was studied via analyzing the detonation products saved in the explosion chambers. There were no methods to study the dynamics of the synthesis of the explosion UDD.

The SR application allows recording the time history of the density and of signals of the SAXS, which is sensitive to the small-scope modulation of the density. The usage of this method permitted us to uncover the laws for the appearance and growth of the condensed phase particles at the detonation of explosives.

This article presents the experimental data on the recording of the direct radiation and SAXS at the shock waves passing across carbon-rich organic materials. In this case, the shock wave provides both high pressure and strong heating, which is enough for the deep dissociation of the original organic material.

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The study is particularly interesting because of the possibility to compare the classic explosives with the conventional (nonexplosive) carbon-rich compounds and those explosives whose normal detonation is impossible in the experimental conditions because of the extremely large critical diameters.

In addition, the studies of the mechanism of formation and condensation of free carbon can clarify the physics of a number of phenomena in the shock wave and detonation processes.

2. Arrangement of the experiments

The layout of the experimental assembly is shown in Fig. 1. The detailed description of the stand and basis for the experiments are given in Ref. [2]. The work being described was devoted to recording the SAXS magnitude and variation of the intensity of the X-ray SR beam passing through the material being compressed by the shock wave. In some of these experiments, the SAXS signal was recorded by two detectors for two spectrum areas. The silicon detector was recording the soft component (about 5–15 keV) and the germanium one, the hard component (15–30 keV).

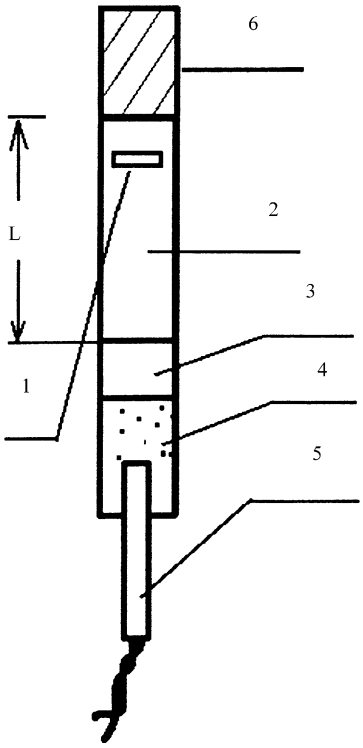

Fig. 1. Layout of the experimental assembly: 1—the spot the SR beam was aimed at, 2—the substance to study, 3—the pressed octogen, 4—the powder octogen, 5—the detonator, 6—the heavy barrier.

In the course of preparation for the experiment the substance to study was cast in the form of a column 12 mm high on to a pressed (up to a density of 1.64 g/cm^3) block 12.5 mm in diameter and 12 mm high of a high explosive (octogen, hexogen or PETN). The initiation of the pressed high explosive was realized through a charge of powder octogen by a high-voltage detonator.

To strengthen the compression and to slow the unload, a barrier (a brass cylinder 25 mm in height and 12.5 mm in diameter) was melted to the column of the substance to study. The barrier was to form a secondary (reflected) shock wave.

The X-radiation beam passed through the middle of the column and was recorded by the direct beam detector. The SAXS detectors located over and below it at angles of $\approx 10^{-3}$ rad.

Below are presented the results of the experiments on density measurement in dependence on the variation of the intensity of the X-ray SR beam passing through the substance under the compression by the shock wave and of the magnitude of the SAXS given by the particles of the condensed solid phase. The compressed media were some aromatic compounds with a different number of nitrogroups in a molecule: naphthalene, isomeric mixtures of mono-, di- and trinitronaphthalenes, dinitrotoluol and dinitrobenzol (naphthalene and its mononitroderivatives are not explosives and the rest are weak explosives with large critical diameters). The experiments with pressed samples of picric acid and nitroguanidine were carried out in the same conditions. An additional study of a refined UDD powder and a similar water-wetted powder at shock compression was carried out.

3. Results of the experiments and discussion

The most interesting results seem to be the data obtained at compression of the naphthalene (Fig. 2). The shock wave in these experiments was formed by octogen pressed up to a density of 1.8 g/cm^3 without plasticizer. In this case, the SAXS signal rose for 2 μs with a practically constant media density. The SAXS inclination and magnitude coincide with those of trotyl [3]. When the reflected wave arrived, the density increased insignificantly and the SAXS signal stopped rising. In 0.5 μs the SAXS started falling slowly and reached the background level in 4 μs. The intensity of the soft SAXS component continued to be small all the time.

As mentioned above, we think that the temperature and pressure at the compression of organic substances by strong shock waves are sufficient for deep decomposition of the material. Such decomposition can lead to the formation of free carbon atoms or of carbon fragments of the initial molecules. Under high pressure and temperature the carbon atoms or their fragments can combine to carbon particles of different phase modifications. The highest density belongs to the diamond phase. Since the SAXS is determined by the density modulation, as in Ref. [3] we will consider the main contribution to the SAXS to be by the particles of the diamond phase.

At the shock compression of the naphthalene the rise of the intensity of the hard SAXS component cannot be explained by the contrast range increase since the signal rises at a practically constant density of the substance. The signal rise is most probably determined by the growing concentration of the condensed particles and the increase of their size, which can be connected with the sustained chemical reactions or with the arrival of the substance from the zone of a more intensive shock wave. The stopping of the signal growth when the reflected wave arrives can be explained by the dominant influence of the increased temperature in comparison with that of the pressure. The further fall of the hard component signal can be determined by, on one side, the lessening of the particle concentration because of the dispersion of the substance and on the other side, by their disappearance when the pressure drops.

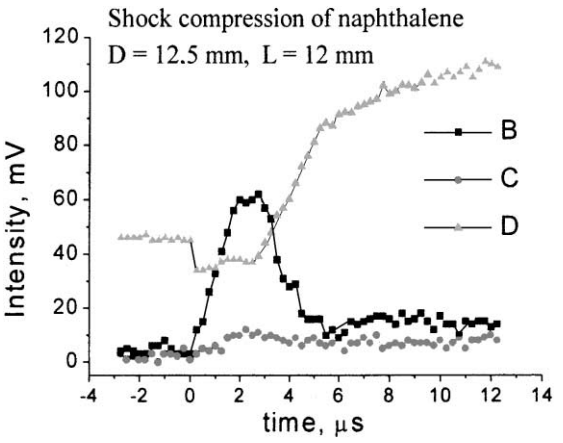

Fig. 2. Shock compression of the naphthalene. D—the passed SR beam intensity; B and C—the intensities of the hard and soft SAXS components, correspondingly.

The practical absence of the soft SAXS component proves that we observe here the dynamics of formation of the smallest (nucleus) particles of the condensed carbon, including the UDD. The same can be testified by their disappearance when the pressure drops.

When the number of nitrogroups in a molecule increases (data for the mono-(MNN), di-(DNN) and tri-(TNN) nitronaphthalenes) some "degeneration" of the compression zone is observed. The intensity of the hard SAXS signals decreases noticeably, the signals appear only when the reflected shock wave arrives. The soft SAXS component also is significantly less and, unlike the hard one, does not fall with the dispersion but stays practically constant.

For the dinitrotoluol (DNT) and dinitrobenzol (DNB), the dynamics of the direct radiation and SAXS is very similar to the detonation process (Fig. 3).

The SAXS signals appear in 0.25 μs after the maximal compression. The soft SAXS component is slightly higher in the DNB. The strong compression zone in the DNT is 0.75 μs against 0.25 μs in the DNB. The picric acid and trotyl initiated by the pressed octogen have the same large zone of compression.

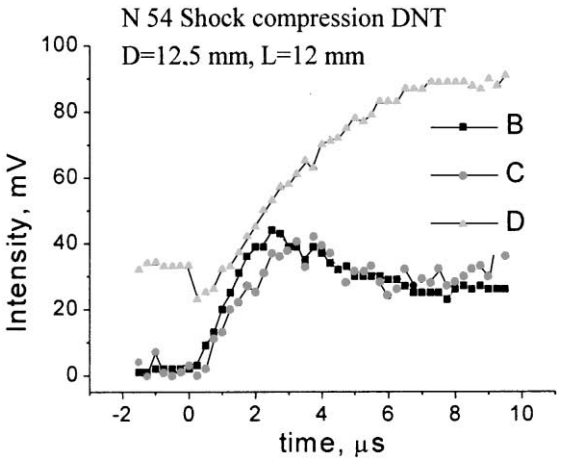

Fig. 3. Shock compression of the DNT. D—the passed SR beam intensity, B and C—the intensities of the hard and soft SAXS components, correspondingly.

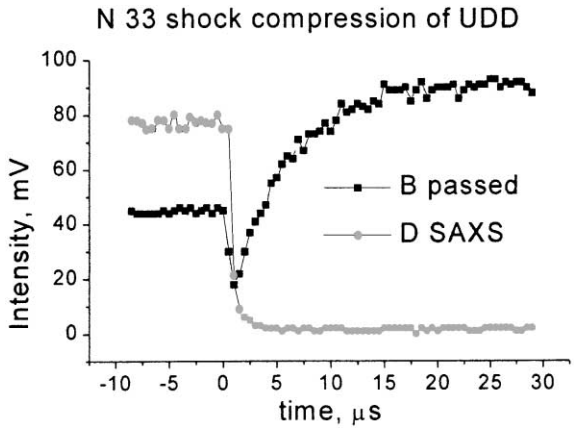

Fig. 4. Shock compression of the UDD. B—the passed SR beam intensity, D—the intensity of SAXS.

The results of the experiment with the passing of the intense shock wave through UDD seem to be interesting. Under the condition when the space between the particles is filled with air and the compressibility of the medium is high, the passing of the shock wave leads to a fast, total disappearance of the hard SAXS signal beyond the resolution limits of the system (Fig. 4). Such behavior of SAXS can be explained by graphitization of the UDD particles.

Under the conditions when the space between the particles is filled with water and the compressibility of the medium is low, there is no such strong heating in the shock wave and the SAXS signal change is caused, first of all, by the density change at the shock compression.

4. Conclusions

The above-presented results show the possibilities of the SR application for the registration of the dynamics of the crystal phase, including UDD, appearance. Obtaining of the quantitative data requires further work. Nevertheless, the experimental methods being developed proved their serviceability and allowed to correct data indicating the presence of laws of the crystal phase growth.

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References

[1] V.F. Anisichkin, I. Yu Mal'kov, V.M. Titov, (Rus.) Doc. Acad. Nauk. 303 (3) (1988) 625.
[2] A.N. Aleshaev, et al., Methods of research of the detonation and shock wave processes with the help of SR. Possibilities and prospects. Nucl. Instr. and Meth. A 470 (2001) 240, these proceedings.
[3] O.V. Evdokov, et al., Dynamics of the formation of the condensed phase particles at detonation of explosives. Nucl. Instr. and Meth. A 470 (2001) 236, these proceedings.