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Investigating Shock-Wave Transient Processes in Explosives by Means of Synchrotron Radiation

K. A. Ten[a], E. R. Pruuel[a], A. O. Kashkarov[a], L. A. Luk'yanchikov[a], L. A. Merzhievsky[a], Yu. A. Aminov[b], E. B. Smirnov[b], A. K. Muzyrya[b], and O. V. Kostitsyn[b]

[a] *Lavrentyev Institute of Hydrodynamics, Siberian Branch, Russian Academy of Sciences, Novosibirsk, 630090 Russia*
[b] *Russian Federal Nuclear Center, Zababakhin National Research Institute of Technical Physics, Snezhinsk, 456770 Russia*
e-mail: kashkarov@hydro.nsc.ru

Abstract—The results from studying the transient processes induced by a shock in porous TATB, obtained using an original and tested method based on employing the soft X-ray component of synchrotron radiation, are presented. The method enables us to determine the parameters of a shock-wave striker, the distribution of velocity and density behind the front of the shock and detonation wave, and the characteristics of flow after a shock wave is reflected from a rigid wall, all in one experiment. Trials with charges 1.8 and 1.9 g/cm^3 in density show that modes such as the absence of detonation and initiation in direct and reflected shock waves, are possible depending on the loading conditions.

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INTRODUCTION

The interest in researching shock-wave processes in explosives is due mainly to the problem of determining the critical conditions detonation initiation. On the other hand, the data obtained in such investigations can be used to construct the shock adiabatic curves of explosives. In this work, the results from experimental research on the distribution of shock waves in triaminotrinitrobenzol (TATB) samples at two initial densities $\rho_0 = 1.8$ g/cm^3 and $\rho_0 = 1.9$ g/cm^3 are given. A pilot study was performed using a familiar approved method based on employing the soft X-ray component of synchrotron radiation (SR) [1, 2]. SR has a number of advantages over similar traditional nonperturbative approaches in which the radiation is generated by means of X-ray tubes: a high intensity of the photon flux, $\approx 10^6$ pcs/mm^2 per one exposure; low angular divergence; and high stability and periodicity of the radiation flashes (exposure time, ≈1 ns; repetition period, up to 125 ns). A probing beam of SR 20 mm wide and 0.1 mm thick is formed on the designed bench. A detailed description of the procedure for reproducing physical parameters by the resulting experimental data can be found in [1–3]. The spatial and temporal resolutions of the method allow the recording of successive stages of process development, including the distribution of the shock wave, and the excitation or absence of detonation.

EXPERIMENTAL

Our experiments were conducted on cylindrical charges made from pressed TATB 20 mm in diameter and 15 mm long; the density was $\rho_0 = 1.8$ g/cm^3 and $\rho_0 = 1.9$ g/cm^3. Note that the distance at which the detonation can emerge was thus limited. A shock wave in the samples was excited by the shock of 2-mm-long aluminum and copper plates, propelled using an explosive device [1] at velocities of 200–2000 m/s. The rear end of the charge bordered a heavy steel plate, ensuring the reflection of the shock wave. The assembly was oriented relative to the SR ray such that it passed through the axis of the charge [3]. This allowed us to obtain information on the distribution of density in the observed object. Since the shock wave striker enters the observed area as well, its form and position (absence of rotation) are controlled in experiments, and the velocity of the shock is determined. The obtained data show a plane collision. The dynamics of a change in density at a frequency of 0.5 μs make it possible to trace the evolution of the profile of the direct and reflected wave in a charge and the velocity of its distribution, and to establish the time and place of detonation origin.

RESULTS AND DISCUSSION

The initial result from measuring is the distribution of mass on the ray, calculated to the density distribution by the method in [3]. Figure 1 shows the experimental data for loading when the direct shock wave is converted to the detonation wave. The variations of the signal at the zero instant of time (before loading) are caused both by natural dispersion in the detector (noise) and any possible heterogeneity of density along the charge length. The curves corresponding to 1 and 2 μs from the beginning of the process show the pronounced discontinuities conforming to the wave dis-

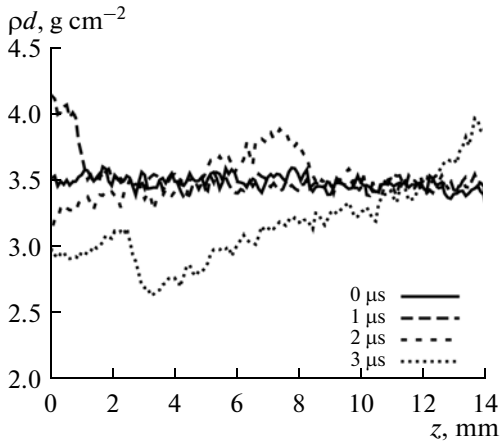

Fig. 1. Evolution of mass distribution along a beam for the excitation of detonation when a shock wave passes over a charge.

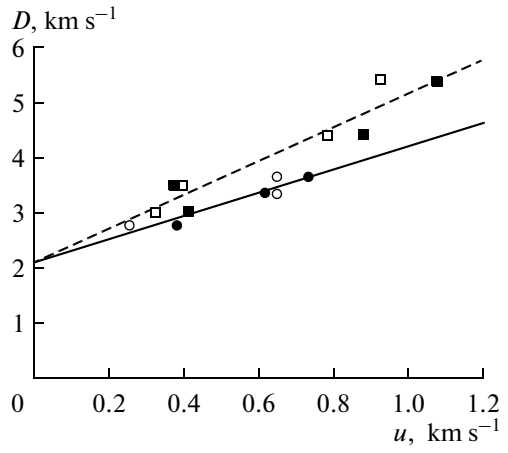

Fig. 2. Shock adiabatic curves of the investigated compositions.

tribution. Here and at subsequent time intervals, its velocity was about 7 km/s. The curve at 3 μs testifies to the increased density behind the wave front that correlates with the detonation process.

Modes in which there was no initiation of explosives, or initiation took place in the wave reflected from the barrier located downstream of the charge, were observed in some experiments. The results are presented in a table containing the values of the initial velocity of shock wave, the mass velocity in a sample, and the result of impact on the charge. The mass velocity behind the wave front was determined by two methods: by the velocity of the striker motion and by the mass conservation law at the front at the measured density and velocity of the shock wave. The estimated critical initiation pressure for this explosive was ~10 GPa.

Shock adiabatic curves built using the obtained data in the (D–u) coordinates (the velocity of shock wave is the mass velocity) are presented in Fig. 2. Here, the dots and solid line show the density $\rho_0 = 1.8$ g/cm^3; the squares and dotted line correspond to $\rho_0 = 1.9$ g/cm^3. While the white symbols denote the value of mass velocity estimated by the striker velocity, the black ones specify the values determined by the mass conservation law. Both methods for defining the mass velocity yield similar results, additional confirmation of the correctness of the obtained values. The data for each density are approximated by traditional linear relationships. In the range of 0.2 km/s $\le u \le$ 0.8 km/s, they take the form

$$D = 2.12 + 2.09u, \quad (\rho_0 = 1.8 \text{ g/cm}^3),$$
$$D = 2.09 + 3.08u, \quad (\rho_0 = 1.9 \text{ g/cm}^3).$$

The difference in the slopes of the shock adiabatic curves is due to the difference in the charge pressing conditions, the formed structures, and the difference in the binding additives. Owing to the considerable effect of the above factors on the properties and sensibility of an explosive, the present data and the results obtained by other researchers [4, 5] are rather difficult to compare.

Figure 3 gives the shock adiabatic curve for an explosive with $\rho_0 = 1.8$ g/cm^3 in the (p–u) coordinates (where p is the pressure). Here, identical marks denote the data from one experiment; the white and black symbols are similar to the ones in Fig. 2. The points on the ordinate axis show the stagnation pressure determined during testing upon wave reflection from the hard surface. These points belong to the different shock adiabatic curves of secondary compression.

Let us estimate the error of the performed measurements. The error of measuring the substance mass along a ray, which is related to the dispersion of the detector's readings, is estimated on the basis of the curves for the zero time instant (the curve in Fig. 1), in units of percents. The velocity of the wave front is recorded by the motion at the level of half-height of the jump, which is determined with an accuracy of 0.2 mm (the size of the detector strip) and averaged

Experimental results

Density, g cm^3	u, km/s	D, km/s	Test result
1.8	0.26	2.77	No detonation
1.8	0.65	3.36	No detonation
1.8	0.65	3.67	Excitation of detonation in the reflected wave
1.8	0.95	5.13	Excitation of detonation in the direct wave
1.9	0.32	3.03	No detonation
1.9	0.40	3.50	No detonation
1.9	0.79	4.43	No detonation
1.9	0.93	5.40	Excitation of detonation in the reflected wave

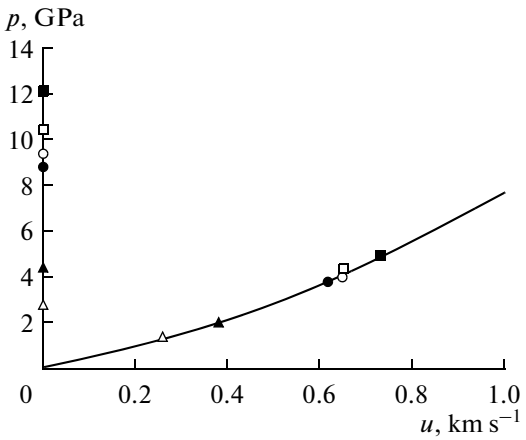

Fig. 3. Shock adiabatic curve at $\rho_0 = 1.8$ g/cm^3 in the (p–u) coordinates.

over time instants of 500 ns. In the part of charge where the initiation of the explosive process does not occur, the velocity of the shock front is virtually constant. Since the front travels 1.5–2 mm in one interval between exposures, the error in estimating the velocity is about 10%. Upon determining the mass velocity by both methods, a systematic error emerges. From a comparison of two independent measurements, we can estimate the error in assessing the mass velocity at a level of 10% as well.

CONCLUSIONS

The results from our studies show the applicability of the method based on the use of synchrotron radiation for obtaining new physical results concerned with the behavior of explosives upon shock-wave loading. The shock adiabatic curves of two explosive compositions based on TATB were constructed, and the conditions of detonation initiation were established in some cases.

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