Shock Hugoniot data for different initial density of TATB-based HE using synchrotron radiation

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Abstract. The work presents the results of experiments on the shock front dynamics at polymer bonded TATB with ultrafast multi-shots one-dimensional method based on the use of a synchrotron radiation. This method allows us to determine Hugoniot data for reactants by registration of the direct and reflected shock waves in the samples. The absence of intensive chemical reaction is observed during the experiment.

Introduction

Experimental studies of shock wave process in high explosives (HE) are usually carried out to determine Hugoniots and equations of state both for reactants and detonation products. When the intensity of shock wave is high enough for shock to detonation transition (SDT), the problem to determine reactants-to-products ratio behind the shock front arises. To exclude the influence of chemical reaction, for example, it can be possible to measure state of reactants at the nearest to the impact zone, where the SDT process is at the initial stage.

In present report, the shock response at TATB-based charges with different porosity is determined by synchrotron radiation[1] (SR), during the shock wave propagation in the sample from impact boundary. This ultrafast multi-shots method allows one to register not only the appearing shock wave, but also the state of substance behind the shock front during up to $10\ \mu s$ after its passing. Such information could be used as data to make statement of presense of intensive chemical reaction (in other words SDT process) or its absence. Thus, it can be determined that the state of substance corresponds to either pure reactants or compound of reactants with products.

The registration of the flow arising after the passing of the shock front can be done not only for determining the presence of intensive chemical reaction. When the shock wave reaches the boundary between HE charge and its massive steel base, it is reflected back. It is well known that the shock sensitivity of the porous charge of HE decreased after loading by weak shock wave, therefore the pressure at the reflected wave front could be higher than at the single wave front, and in this case the intensitive chemical reaction might not arise.

Experiment

The experimental study is devoted to X-raying by SR beam of the HE sample during the impact by the metal striker. The passing radiation, which contains data about amount of substance along the beam line,

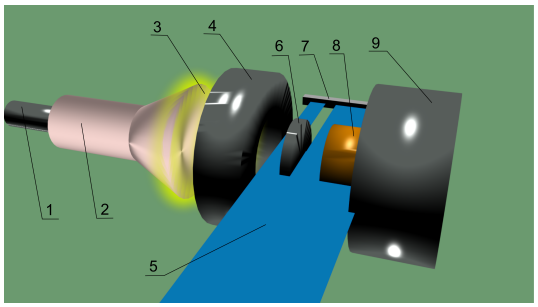

Fig. 1. 1 - detonator, 2 - explosive lens, 3 - additional charge, 4 - obturator, 5 - SR beam, 6 - striker, 7 - SR beam detector, 8 - sample, 9 - steel base.

is recordered by the one-dimensional multi-shots detector. The shock front posisiton is well defined by the significant local attenuation of the intensity due to the compression of substance. The metal striker absorbes the SR radiation almost completely, hence its boundaries are well defined too. The measured thickness of the striker by the SR means must be equal to the initial one. Otherwise, that means rotation or destruction of the striker. The intensive chemical reaction leads to a significant side expansion of products behind the shock front. It could be determined by increasing of the intensity of passing radiation at this zone.

The scheme of the experiment is shown in fig. 1. The explosive lens (2) which are initiated by the detonator (1) makes a plane shock wave, which initiates the additional charge (3). Placed at the obturator (4) the aluminium striker (6) is accelerated by products of detonation and strike the cylindrical sample (8), which is set on the steel base (9). Since the striker has started, the detector (7) began registration of the intensity of passing radiation of SR beam (5).

The passing radiation is registered as one-dimensional x-ray movie. The spacial resolution is $0.1\ mm$ and the temporal one is $0.496\ \mu s$. The exposure time is about $1\ ns$. Fig. 2 shows the experimental data of intensity for the both direct and reflected shock waves. The shock front positions and their propagation directions are marked with arrows. The zone of low intensity on the left side of the plots comply with striker position. The results reveal that the intensity behind the shock fronts is relatively low, which points to the compressed state

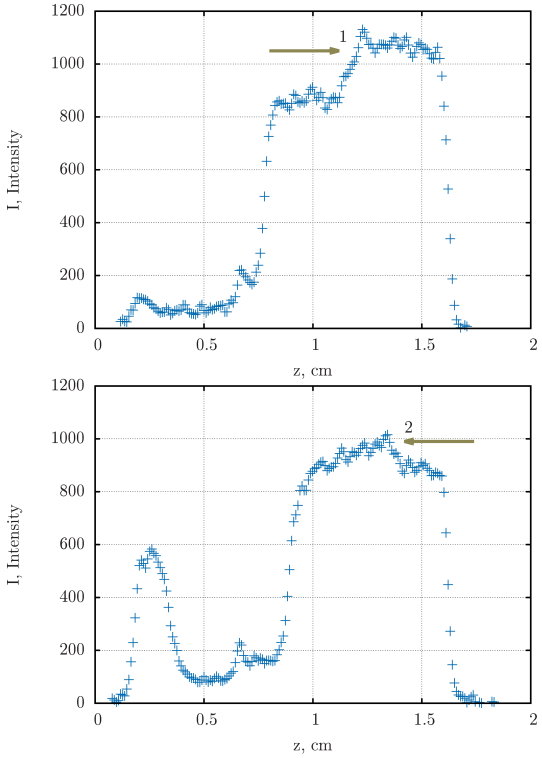

Fig. 2. 1 - direct shock wave, 2 - reflected shock wave.

of substance. The experimental data for SDT process are shown in fig. 3 for comparison with the previous ones. The propagation direction of the shock wave front is to the right. As the SDT process evolves, the flow type changing behind the front on the left side is observed. The increase rate of intensity is lower on the left than of the other part. It is even possible to define the point where the intesity of chemical reaction increases rapidly. Therefore, there is some mixture of reactants and products to the right from this point.

The results of the experiment can be represented as the x-t diagram for the shock front and the striker (fig. 4). It is possible to change the striker speed before the impact by varying its mass. So, the speed of the striker that is neccessary to arise SDT at the direct or reflected shock waves can be determined. To obtain parameters of compressed reactants, we use data from experiments where the SDT process does not appear or it can be only in reflected waves. In the last case, we get data for calculations only for

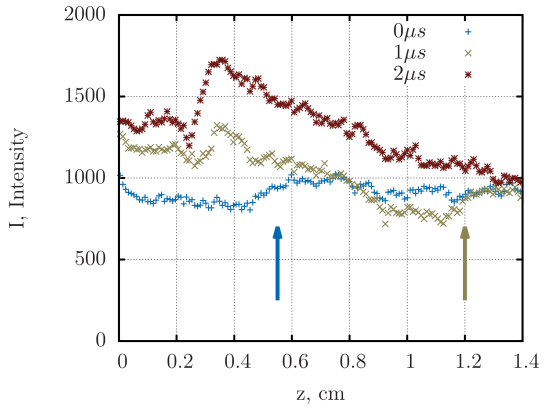

Fig. 3. SDT process. The shock front posisitons are marked with arrows, left for the 0 μs, right for the 1 μs. At the 2 μs, the front is outside the area of the observation. The side expansion at the left from the point 0.3 cm is less than at the right.

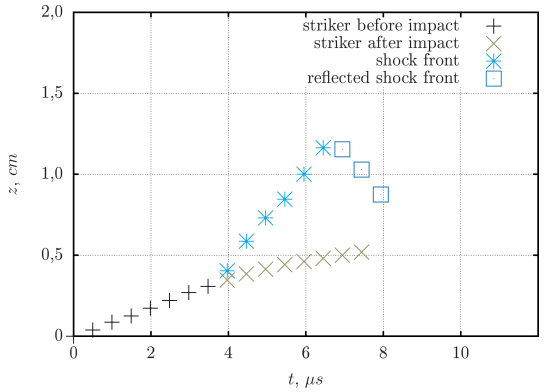

Fig. 4. x-t diagramm of process.

direct wave. The SDT process in the reflected wave appears when the speed of the striker before impact is approximately from 1.5 to 2 km/s depending on porosity of the samples. If the speed of the striker is larger than about 2 km/s, the SDT would appear at the direct wave for any prorsity of studied samples (from 2 to 8%).

If the speed of the striker is very low, the compression in the shock wave will be not enough to obtain high contrast signals to determine the front position. So, when the speed is lower than 0.5 km/s, the front position cannot be derived for any prosity of the samples. Thus, the range of pressure in the front of the direct wave for which we can measure state of reactants is very restricted. But at the same time, the pressure in the reflected wave practically doubles, and the sensitivity of previously compressed samples is lower. This enables to increase significantly the upper limit of the pressure for compressed state of reactants without arising intensive chemical reaction.

Results

The x-t diagrams obtained are used to determine the velocities of the shock front and the striker before and after the impact, which corresponds to the mass velocity of substance behind the shock wave according to Rankine-Hugoniot conditions. However, such way of determination of mass velocity could include a significant systematic error. Basically, the shock wave propagating to the striker, which velocity in aluminium is high, occurs after the impact. The shock wave goes to the free surface of the striker and reflects as the rarefaction wave. This wave can reach the striker-sample boundary in about microsecond, depending on thickness of the striker. After this, the speed of the striker-sample boundary becomes lower than the mass velocity. During that time, only one or two experimental points on the x-t diagram are usually measured, that is insufficient to determine correctly the speed of the striker. The larger thickness of the striker could cause increasing the time interval before the arrival of the expansion wave, but in this case its speed becomes lower, and the gain of the additional charge mass to increase strikers speed is resulted in the bulk debris. They would move faster than the striker and cause trouble to correct registration of process.

In this paper we take into account the expansion wave by the construction of a parametric equation of states (EOS) for HE like the Mie-Gruneisen one, which is used to solve one-dimension Riemann problem by the Godunov's scheme

$$P = b\left(\left(\frac{\rho}{\rho^o}\right)^n - 1\right) + C_V T G \rho,$$

where n, ρ^o, C_V, G – a set of variable parameters, which are considered to be constant. The calculations for x-t diagrams of processes for each experimental conditions with the same porosity are carried out according to this EOS and simple equations of

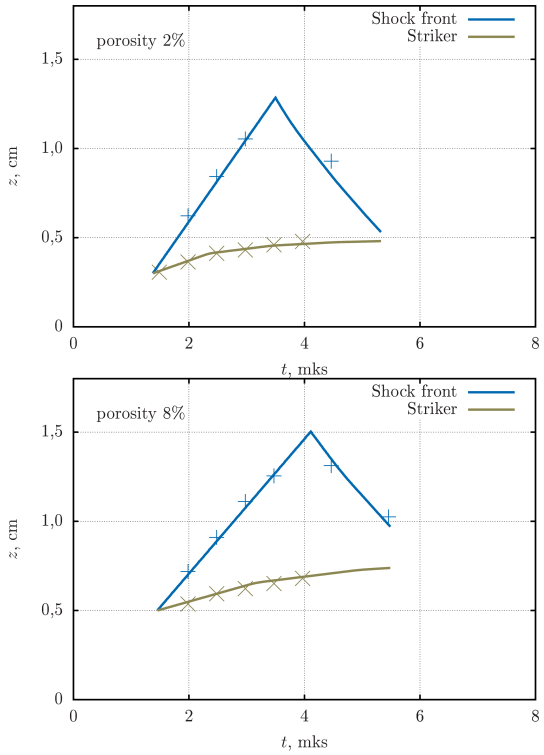

Fig. 5. Calculated and experimental x-t diagrams of the process for different porosity.

state containing only compressive mechanical pressure for the striker and the base. The procedure of minimization of deviations between calculated and experimental data are used to derive the parameters of EOS for reactants.

The pairs of parameters n, ρ^o and C_V, G are bound together, so they do not correspond to real physical properties. Therefore, such method of construction of the EOS does not allow one to determine the isoterm or temperature of the shock compressed reactants, but the Hugoniots in $U_s - U_p$ and consequently $P - \frac{\rho}{\rho_0}$ coordinates can be obtained.

Comparison between the calculated and the experimental x-t diagrams are shown in fig. 5. The kink point on the striker movement diagram correspons to the time when the rarefaction wave reaches the striker-sample boundary. This wave can overtake the direct shock wave front in the sample. However, in the case of the present experimental conditions and the relation between the striker and sample sizes, the side rarefaction wave will reach the central part of the shock front in the sample earlier. The influence of this wave on the arising flow is not considered in this paper. To avoid the significant systematic error, the lengths of the samples are more than twofold lower than the diameter.

The influence of the wave of side rarefaction also is the increasing of the curvature of shock front as the shock wave passes along the sample. This leads to flattening the jump of SR beam intensity in the shock front. Hence, for several cases, the reliable registration of the reflected shock front position can be difficult.

The Hugoniots in $U_s - U_p$ and $P - \frac{\rho}{\rho_0}$ coordinates for different initial porosity of the samples are shown in figs. 6 and 7, respectively. The experimetal data[2] for quite similar TATB-based HE are also shown. The differences between our and literature data can be explained by both the different experimental method due to systematic errors of different nature and variation of the charges manufacturing environment. The Hugoniots of samples with porosity 2 and 8% are near the resolution limit. As for the intermediate porosities, the distinction between the 2 or 8% and their Hugoniots is not clearly been in such experiments.

When the shock front goes to the sample-steel base boundary, it reflects back to the sample as a shock wave. This reflected wave moves along the compressed charge. In the reflected shock wave front, the pressure significantly increases, but according to HE desensitising, the SDT process might not the case. This make it possible to expand the range of pressure for which we can get data for the shock compressed reactants. For the tested samples, the pressure at the von Neumann (vN) spike is about $40\ GPa$, and the maximum pressure in the reflected wave at reactants is about $25\ GPa$ (fig. 8).

Conclusion

The sipmlified version of the Mie-Gruneisen EOS leads to linear relationship between U_s and U_p on Hugoniot. At the same time, it is well known that at low mass velocity, the relation for several HE is nonlinear. This feature can be taken into account by complicating the form of EOS that involves increasing a number of parameters. For example, the Wescott, Stewart, and Davis[3] model for reactants contains 8 parameters derived from the experiment.

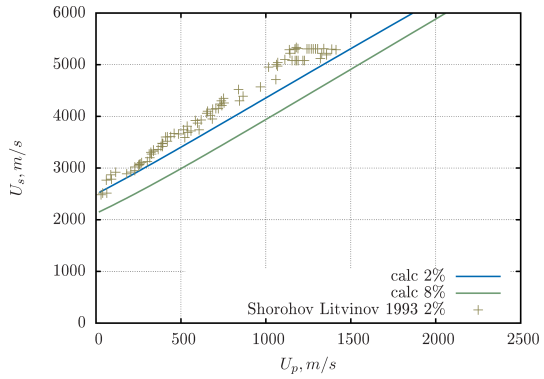

Fig. 6. $U_s - U_p$ adiabat for various porosity of initial charge.

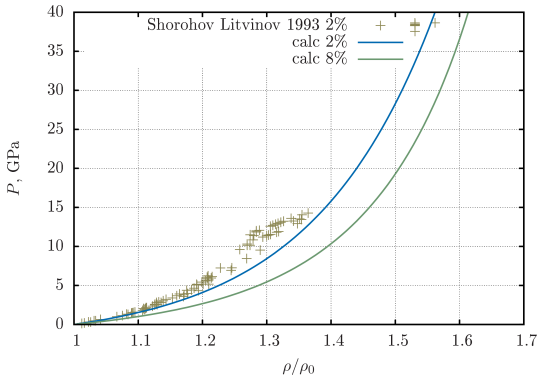

Fig. 7. $P - \frac{\rho}{\rho_0}$ adiabat for various porosity of initial charge.

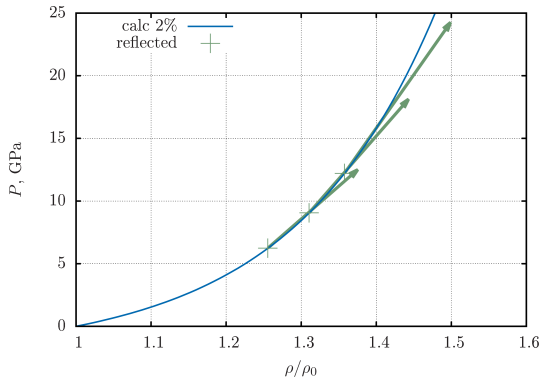

Fig. 8. $P - \frac{\rho}{\rho_0}$ Hugoniot of direct and reflected waves for 2% of porosity.

However, the presented experimental method does not allow to make measurements in the mass velocity range less than $0.5\ km/s$. If the mass velocity is larger, the distinction between the shape of Hugoniot and the straight line is difficult to observe at experiments. At this time, even we use the 4-parametric EOS, it is possible to find a number of parameter sets, which give good agrement between calculated and exprimental x-t diagramms. Calculated Hugoniots for each set of parameters are very close.

The parametric EOS for reactants which allows to determine the Hugoniots of the direct and reflected waves in range the pressure of $5 \div 25\ GPa$ is obtained for 2 and 8% porosity of initial samples of polymer bonded TATB. The vN spike pressure in these HE is about $40\ GPa$. The upper limit of pressure in the reactants can be observed only in the reflected wave, because the fast SDT process started when the pressure in the direct wave was higher than about $15\ GPa$ depending on the porosity. As we can see, in the range of pressure less than $5\ GPa$ it is appropriate to use other methods to determine the shock response at the present time. Widening the range of pressure in this method to the lower values can be reached by enlarging diameter of samples which results in reducing a curvature of a shock front. It would lead to increasing the intensity jump on the shock front. This will require higher intensity and energy of SR beam. Presently, the active works is carried out in this direction.

The reflected waves does not always move along the compressed sample. It is possible to choose conditions for which the expansion wave can overcome the direct shock wave when the last one goes to sample-base boundary. This gives data not only for the Hugoniots of the direct and reflected waves but also for more complicated states of HE under shock loading.

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