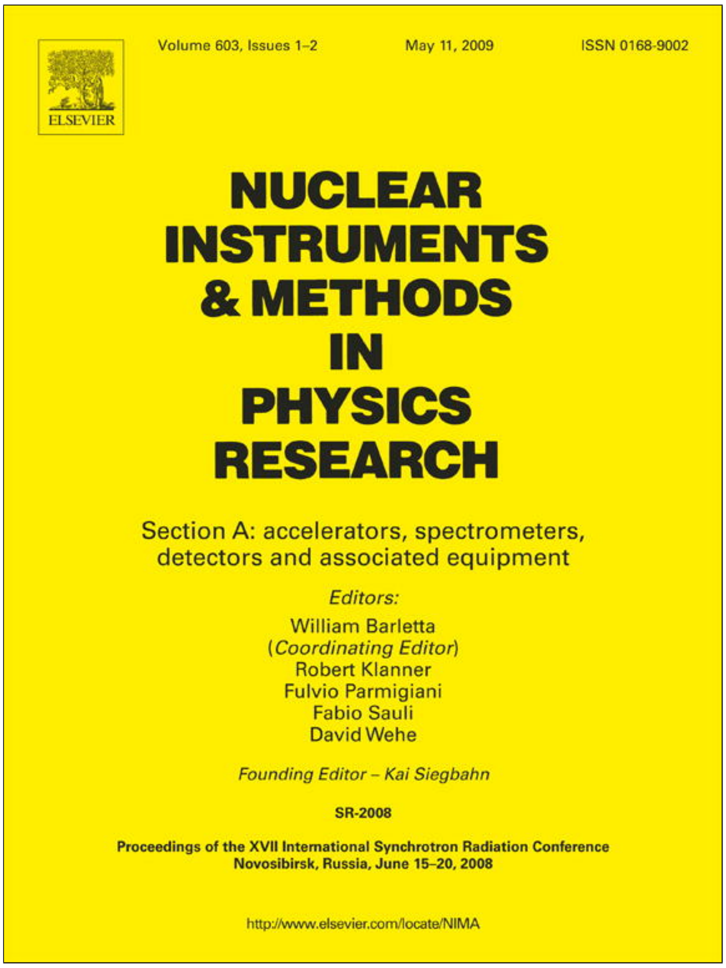
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Synchrotron radiation as a tool to construct the shock adiabats of aerogel

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ABSTRACT

Unique properties of aerogel, namely, high porosity with open pores, low thermal conductivity, optical transparence, make it attractive for practical applications and for research. One of the areas in which aerogel has won a wide application is connected with shock waves and other kinds of high-energy action. This is the reason of the attention to the investigation of aerogel behavior under shock load, in particular to the construction of its shock adiabats. Here we present the results of the construction of shock adiabats for silicon aerogel of different densities with the help of the developed methods based on the use of synchrotron radiation [A.N. Aleshaev, P.I. Zubkov, G.N. Kulipanov, et al., Fiz goreniya vzryva 37 (5) (2001) 104 (in Russian)]. New experimental data related to the range of moderate loading parameters.

1. Introduction

Porous media (materials) exhibit a variety of properties; find a wide application in engineering, technology, and is a subject of numerous investigations. A special position among them is occupied by highly porous aerogels which possess unique physical properties. Their main features are optical transparence, extremely low density and a large number of the small-sized open pores. In addition, these materials are specific physical bodies constituting macroscopic clusters composed of rigidly bound macroparticles. A characteristic feature of separate particles is several nanometers. A rigid framework accounts for a small fraction of the aerogel volume, that is, almost the whole of its volume (up to 98–99% and more) is occupied by pores. Due to the mentioned structural features, aerogels possess unique physical properties, the most important among which are low heat conductivity and sound velocity [2]. The velocity of the propagation of small perturbations in aerogels exhibits a power dependence on density and could be smaller than the sound velocity in gases. In the present work we use the advantages of synchrotron radiation (SR) to investigate the behavior of aerogel based on silicon dioxide SiO_2 under the shock-wave loading. The applicability of SR for the investigations of explosions and shock-wave processes was demonstrated in [1,3].

2. Scheme of experiments

The arrangement of experiments aimed at the investigation of detonation and shock-wave processes was described in detail in [1,3] and is shown in Fig. 1.

In the present work, cylindrical aerogel samples with a diameter and length 10, 15 and 20 mm were loaded. The shock wave in the samples was excited by a blow of a flat plate accelerated by the products of detonation of the explosives through an air gap. The direct measurement with the help of the transmitted SR showed that the plate remained almost flat during the whole time of experiments. A compact explosive generator was developed for driving the plunger (Fig. 1). The generator consists of the detonation lens (1, Fig. 1) and a tablet of the mixture of trotyl and hexogen (TH) 50/50 with a mass of 20 g. The diameter of the cylindrical plunger was 20 mm. The velocity acquired by the plunger depending on its thickness and on its material was within the range 300–2000 m/s. SR beam was used to measure the parameters of the shock-compressed aerogel. The assembled sample under investigation and the loading device were arranged horizontally along the plane of the formed SR beam; the beam height was 0.4 mm and width $\approx$18 mm. The shock wave in aerogel existed in the zone of the SR beam for 3–4 μs. Within this time, we succeeded in taking 6–8 snapshots (with the exposure of c $\sim$1 ns) of the distribution of transmitted radiation along the sample axis. Time between the frames was multiple to several pulses of SR and was equal to 0.25–0.5 ns. The radiation was recorded with a DIMEX detector [4], which was placed also along the axis of he assembly at a distance of 770 mm

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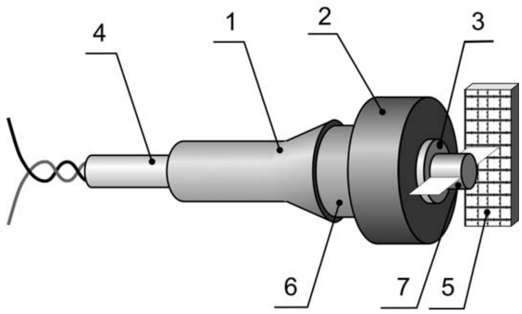

Fig. 1. Scheme of experiments: (1) plane wave generator (PWG); (2) guard ring; (3) plunger; (4) detonator; (5) DIMEX detector; (6) explosive TH 50/50; (7) sample.

from it. The size of one registration channel was 1 mm (height) and 0.1 mm along the charge axis, total number of channels was 256 (25.6 mm). Detector initiation was performed by closing the contact sensor mounted at a distance of 15 mm behind the beam area. Changes of the intensity of the beam passed through the sample gives the information about the density distribution over the measurement area.

3. Experimental results

In the series of experiments involving variations of loading conditions (velocity, material and thickness of plungers), we studied the propagation of shock waves generated in aerogel, and their characteristics. A part of the radiation is absorbed when passing through the sample under investigation. As a result of experiments, we obtain the data on the distribution of the intensity of radiation $\boldsymbol{I}$ passed through the sample under investigation along the sample axis at sequential moments of time. The character of changes in the intensity of the transmitted radiation while the shock wave propagates is illustrated in Fig. 2 showing the dependence of $\boldsymbol{I}$ (in arbitrary units) on the distance passed.

Here the initial density of the sample material is $\boldsymbol{\rho_0} = 0.25\,\mathrm{g/cm^3}$, the velocity and thickness of the copper plunger are 0.6 km/s and 6 mm, respectively. The process propagates from left to right, time interval between the shown profiles is 0.5 μs. The first two curves correspond to the movement of the plunger; after its collision with the sample, a compression pulse is formed in the sample and starts to propagate; this pulse gradually leaves the plunger behind. These data were used to construct the time dependence of plunger displacement and the movement of the wave generated by it, as shown in Fig. 3.

Thus, in each experiment, we measured the initial velocity $\boldsymbol{W}$ of the plunger, the velocity of the shock wave in $\boldsymbol{D}$ in the sample under investigation, and the mass velocity $\boldsymbol{U}$ behind the shock wave front; in our case the latter is almost equal to the current velocity of the plunger kept constant during the whole time of measurements. Thus obtained data are enough to determine the parameters of the compressed substance completely. Knowledge of the initial velocities of the plunger and the wave allows one also to use the braking method in order to calculate the parameters of aerogel compression [5] because the shock adiabats of the plunger materials are well known. Finally, the shock adiabats for aerogel of different initial densities were determined; each experimental point on the curves was plotted using two procedures, which allowed us to elevate the accuracy of the data obtained. It should be noted that the data obtained with the help of these two procedures almost coincide with each other.

The shock adiabats of condensed media are usually represented as the dependence of the shock wave velocity $\boldsymbol{D}$ on mass velocity $\boldsymbol{U}$, which is usually a linear function:

$$\boldsymbol{D} = \boldsymbol{A} + \boldsymbol{B}\boldsymbol{U}, \tag{1}$$

where $\boldsymbol{A}$, $\boldsymbol{B}$ are constants determined from the experimental data, for example by means of the least squares. The shock adiabats constructed on the basis of the results of experiments are shown in Fig. 4.

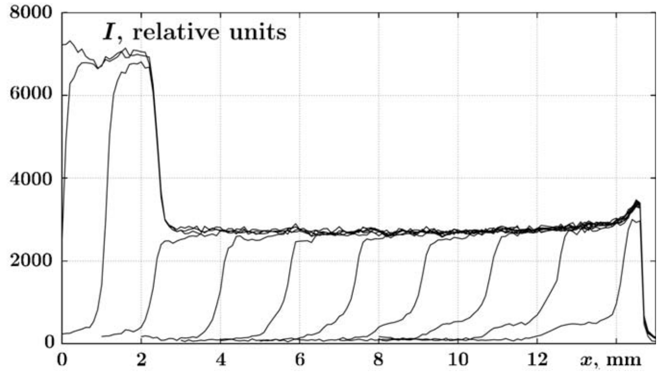

Fig. 2. Changes of the relative intensity of transmitted radiation while the shock wave propagates.

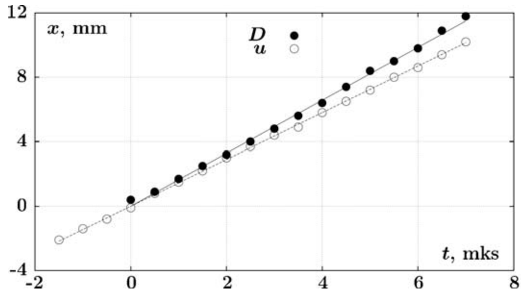

Fig. 3. Experimental *x*, *t*-diagram of the collision process.

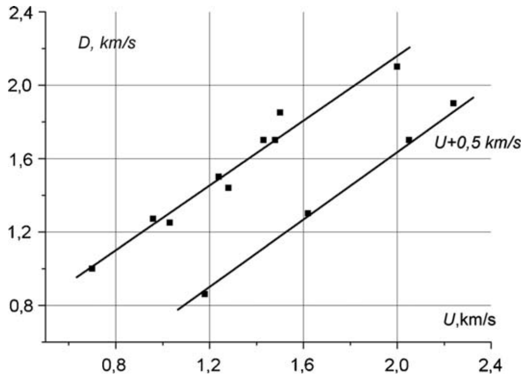

Fig. 4. Shock adiabat of aerogels; initial density: (1) $\rho_0 = 0.15\,\mathrm{g/cm^3}$; (2) $\rho_0 = 0.25\,\mathrm{g/cm^3}$.

4. Discussion of results

The character of changes of the intensity of transmitted radiation as the shock wave propagates over aerogel is shown in Fig. 2. Even taking into account the instrumental smearing of the signal (a "point" signal excited 3 registration channels) one can see that the front of the loading pulse is essentially smeared, which is connected with the high porosity of the material. It is known that the front width in strong shock waves is equal to several units of the characteristic particle size. In the case under consideration, in spite of the fact that it is impossible to determine the front width precisely in the described experiments, it is essentially larger than the size of any inhomogeneities of aerogel. A likely reason is that our experiments are related to the range of relatively weak and moderate intensities of shock waves.

If we consider Eq. (1) as having not only the empirical sense of a linear interpolation of experimental results, then, for $\boldsymbol{U}\rightarrow\mathbf{0}$ coefficient $\boldsymbol{A}=\boldsymbol{D}=\boldsymbol{C}$, where $\boldsymbol{C}$ is the sound velocity in a given medium. We did not measure the sound velocity in our experiments but a detailed summary of sound velocities in aerogel depending on its density was reported in [2]. A comparison shows that the values determined on the basis of the experimental data give $\boldsymbol{A}\neq\boldsymbol{C}$. It is interesting to reveal how the inclusion of the sound velocities into the group of experimental data will affect the values of the parameter (constants). The corresponding dependencies are shown in Fig. 5.

A linear connection between $\boldsymbol{D}$ and $\boldsymbol{U}$ well approximates the experimental points in this case, too. The coefficients of the resulting dependencies of type (1) are shown in Table 1 where the rows with number 1 correspond to the data without the consideration of sound velocity while those with number 2 show the data obtained taking the sound velocity into account.

It is typical that the slope of the straight lines to the abscissa axis (coefficient $\boldsymbol{B}$) remained almost unchanged. Changes in coefficient $\boldsymbol{A}$ turned out to be noticeable but not principal in the case of aerogel with larger initial density.

Attempts to construct a generalized equation of type (1) describing the experimental data for aerogel with the initial density varied within a broad range were made in a number of works. For example, in [5], a generalized shock adiabat is given for $0.008\leqslant\rho_0\leqslant 0.32\,\mathrm{g/cm^3}$

$$\boldsymbol{D}=-0.12+1.156\boldsymbol{U}. \tag{2}$$

A generalization of our experimental data (Fig. 6) can be described using the dependence

$$\boldsymbol{D}=0.15+1.15\boldsymbol{U}. \tag{3}$$

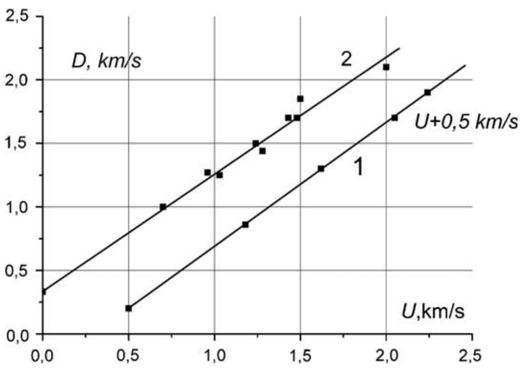

Fig. 5. Shock adiabat of aerogels (taking into account the sound velocity); initial density (1) $\rho_0=0.15\,\mathrm{g/cm^3}$; (2) $\rho_0=0.25\,\mathrm{g/cm^3}$.

Table 1

	A	B
$\rho_0=0.15\,\Gamma/\mathrm{cm^3}$		
1	0.201	0.973
2	0.200	0.974
$\rho_0=0.25\,\Gamma/\mathrm{cm^3}$		
1	0.256	0.998
2	0.286	0.981

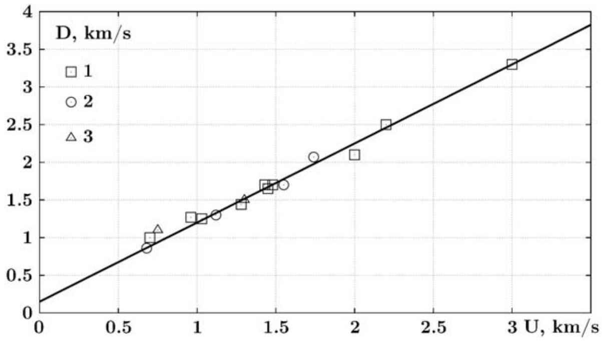

Fig. 6. A generalized shock adiabat of aerogel.

As the results show, $\boldsymbol{B}$ coefficients in (2) and in (3) (the slope of the straight lines to the abscissa axis) almost coincide with each other. The values of coefficients $\boldsymbol{A}$ differ principally. In this situation, $\boldsymbol{A}<0$ in (2), which means that here $\boldsymbol{A}$ is devoid of the physical sense and is only an empirical coefficient of interpolation. The same is true for dependence (3), because the sound velocities for the investigated aerogel samples are essentially different from each other and from that obtained by means of interpolation of coefficient A. Scattering of the experimental data with respect to (3) is rather large. This means that (3), as well as (2), can be used only for rough estimations of the parameters of aerogel shock compression.

The results obtained by us relate to the range of weak and medium intensities of shock waves. They supplement the data of [6–9] obtained for much larger intensities of shock waves.

5. Conclusion

The results of the construction of shock adiabats of silicon aerogel of different density with the help of the developed methods based on the use of synchrotron radiation are reported. New experimental data related to the range of moderate loading parameters are described and discussed. An attempt to describe the results with the help of a generalized shock adiabat showed that the generalized shock adiabat can be used only for rough estimates of the parameters of shock compression of aerogel.

Acknowledgments

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References

[1] A.N. Aleshaev, P.I. Zubkov, G.N. Kulipanov, et al., Fiz. goreniya vzryva 37 (5) (2001) 104 (in Russian).
[2] B.M. Smirnov, Usp. fiz. nauk 152 (1) (1987) 133 (in Russian).
[3] L.A. Merzhievsky, P.I. Zubkov, L.A. Lukianchikov, et al., Mater. Sci. New Mater. Ser. 63 (2) (2004) 383 (in Russian).
[4] V. Aulchenko, O. Evdokov, S. Ponomarev, L. Shekhtman, K. Ten, B. Tolochko, I. Zhogin, V. Zhulanov, Nucl. Instr. and Meth. A 513 (2003) 388.
[5] Ya.B. Zeldovich, Y.P. Raizer, Physics of Shock Waves and High-temperature Hydrodynamic Phenomena, Nauka, Moscow, 1966, 687pp (in Russian).
[6] N.C. Holmes, E.F. See, Shock Comp. Cond. Matt. 4 (1991) 91.
[7] G.V. Simakov, R.F. Trunin, Fiz. Zemli (Phys. Earth) (11) (1990) 72 (in Russian).
[8] R. Rabie, J.J. Dick, Shock Comp. Cond. Matt. (1991) 87.
[9] V.C. Vildanov, M.M. Gorshkov, V.M. Slobodenjukov, E.H. Rushkovan, Shock Comp. Cond. Matt. (1995) 121.