INVESTIGATION OF THE SHOCK COMPRESSIBILITY OF QUARTZITE, PARAFFIN, AND POLYTETRAFLUOROETHYLENE BY USING A MANGANIN PRESSURE SENSOR

N. G. Kalashnikov and M. N. Pavlovskii

UDC 539.63:539.58:550.32

The possibility is shown of using a manganin pressure sensor to measure duplex shock compression. Results of experimental determinations of the shock compressibility of quartzite, paraffin, and polytetrafluoroethylene to 390-920 kbar pressures are elucidated. The data obtained indicate the probable existence of a silicon dioxide phase with a density exceeding the density of stipoverite by 11-17%.

The compression of quartzite, paraffin, and polytetrafluoroethylene (fluoroplast-4) under head-on collisions of shock waves in these materials has been measured by a method based on the increase in electrical resistivity of manganin under compression [1]. The set-up of the experiment is shown schematically in Fig. 1a. The specimens were doubly compressed by plane shocks being formed during the explosion of two identical, simultaneously initiated, cylindrical charges 1 of 120 mm-diameter explosives located opposite each other. The specimen under investigation consisted of three layers, between which were two manganin sensors connected in series. The thickness of the layers 2 between the aluminum shields 3 and the sensors was ~2 mm, and the thickness of the layer S between the sensors was ~18-25 mm. The sensors 4 were fabricated in the form of sinusoids from 0.2-mm-diameter manganin wire, compressed to a thickness of ~0.1 mm. The total resistivity of the sensors was ~3 Ω. Copper foil leads 5 were soldered to the ends of the sensors.

The electrical circuit described in [2] was used to supply the voltage pulse to the manganin pressure sensors and to record the signals obtained. The voltage pulse was fed to the sensors through a ballistic resistor with a capacitor of around 4 μF capacitance. The magnitude of the ballistic resistor was much greater than the total resistivity of the sensors; hence, current remained practically constant in the circuit throughout the recording time. The voltage from the leads to the sensors connected in series was fed along cables directly to the deflecting plates of a C1-24 type oscilloscope. A change in voltage reflected an increase in sensor resistance during their shock loading.

An electric circuit was used as measuring apparatus. Signal recording was accomplished by using C1-24 type oscilloscopes.

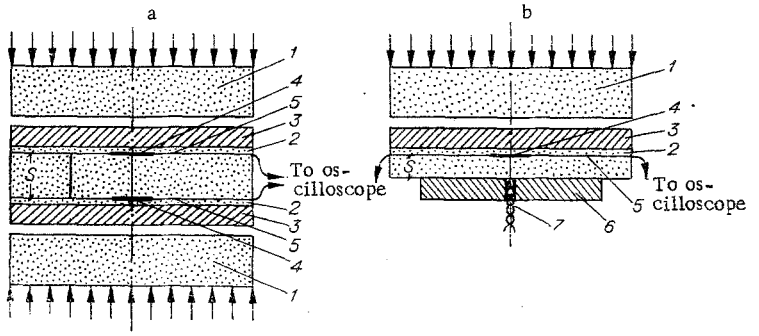

Fig. 1

Moscow. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 1, pp. 180-183, January-February, 1975. Original article submitted July 16, 1974.

TABLE 1

Material being investigated	Specimen compression parameters produced by the first loading shock					Specimen compression parameters produced by the reflected shock				
	D_1, km/sec	U_1, km/sec	P_1, kbar	σ_1	ρ_1, g/cm³	D_{12}, km/sec	ΔU, km/sec	P_2, kbar	σ_2	ρ_2, g/cm³
Paraffin ρ_0=0.9 g/cm³	6,10	2,14	118	1,543	1,39	8,25 9,08	1,58 2,14	299 388	1,908 2,020	1,72 1,82
Teflon ρ_0=2.19 g/cm³	5,00	1,78	195	1,554	3,40	6,88 8,33	0,90 1,78	405 701	1,790 1,978	3,92 4,33
Quartzite ρ_0=2.65 g/cm³	5,72 5,75	1,68 2,05	255 312	1,414 1,553	3,75 4,12	5,92 7,21	1,68 2,05	628 923	1,980 2.170	5,25 5,75

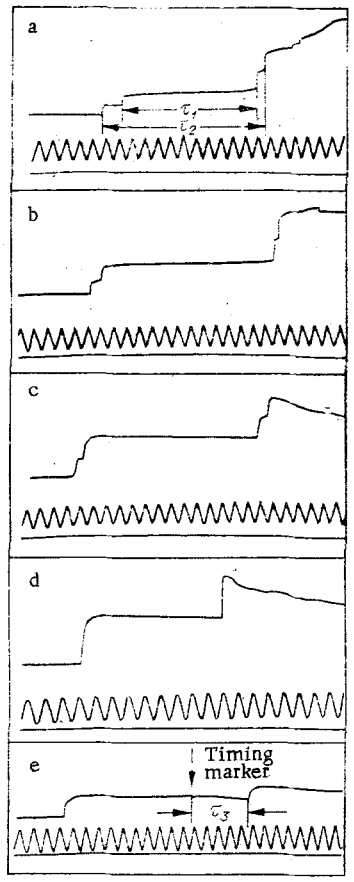

Fig. 2

The oscillograms represented in Fig. 2a-d were obtained on paraffin, fluoroplast-4 (Teflon), and quartzite specimens, respectively. The first excursion of the beam on the oscillograms corresponds to the arrival of loading shocks at the sensors. The duration of the step at the middle of the front of the first excursion characterizes the nonsimultaneity of arrival of shocks from opposite sides at the sensor. The second excursion of the beam on the oscillograms corresponds to the arrival of reflected loading shocks at the sensors. That the profile of the second excursion has two-steps is determined by the nonsimultaneity of reflected compression-wave arrival at the sensors. The noticeably lesser duration of the step in the second excursion is explained by the substantially higher propagation velocity of the reflected waves over the substance which has already been compressed first by the first loading waves. A single-wave configuration of excursions (see Fig. 2d) is observed upon the simultaneous approach of shocks to the sensors from opposite sides. The timing marker frequency is 5 MHz in all the oscillograms.

The compression parameters of paraffin and polytetrafluoroethylene produced by the first loading wave, which were determined from electrical contact measurements of the wave velocities in these materials, and also analogous data for quartzite taken from [3], are presented in the left half of the table, where the initial densities of the specimens under investigation ρ_0, the magnitudes of the wave D_1 and mass U_1 flow rates of the first loading wave, the density ρ_1, and the degree of compression $\sigma_1=\rho_1/\rho_0$ of the substance behind its front are given.

The compression parameters of the substance produced by the reflected shock for the case of a frontal collision between shocks were determined by using the following expressions:

$$D_{12}=U_1+D_1\frac{S-U_1(\tau_1+\tau_2)}{(\tau_1+\tau_2)D_1-S},$$

$$P_2=P_1+\rho_1U_1D_{12},$$

$$\sigma_2=\sigma_1\frac{D_{12}}{D_{12}-U_1}\text{ and }\rho_2=\rho_0\sigma_2,$$

where D_{12} is the velocity of reflected shock propagation, τ_1 and τ_2 are time intervals on the oscillograms (see Fig. 2a), P_2, σ_2, and ρ_2 are the pressure, degree of compression, and density of the material behind the reflected wave front, respectively.

The results of calculations characterizing the double-shock compressibility of the materials being studied under the frontal collision of shocks are extended in the right half of the table. The accuracy of measuring the pressure was ±2%, and the density was ±1%.

Intermediate experimental points on the $P-\rho$ dependences of paraffin and Teflon were obtained as a result of experiments for which the diagram is shown in Fig. 1b. Double-shock compression of the specimens under investigation was accomplished in this case by using the shock reflected from the copper substrate 6 located after the specimen. Closure of the electrical contact of the sensor 7, placed on the bound-

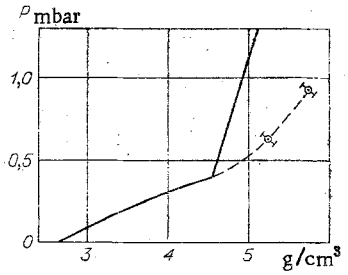

Fig. 3

ary between the specimen under investigation and the copper substrate, permitted obtaining a timing marker corresponding to the arrival of the shock on the substrate on the oscillograms (see Fig. 2d). The thickness S of the specimen was ~10 mm in these tests.

The compression parameters of the specimens produced by a shock reflected from the copper substrate were determined by using the expressions

$$D_{12} = \frac{S}{\sigma_1 \tau_3}, \quad \Delta U = \frac{P_2 - P_1}{\rho_1 D_{12}},$$
$$P_2 = P_1 + \rho_1 \Delta U D_{12},$$
$$\sigma_2 = \sigma_1 \frac{D_{12}}{D_{12} - \Delta U} \text{ and } \rho_2 = \rho_0 \sigma_2,$$

where τ_3 is the time of reflected wave passage over the specimen (see Fig. 2d), and ΔU is the change in the mass flow rate of the material because of reflected shock passage over it.

The results presented in the table are in good agreement with the data in [4, 5] characterizing the double-shock compressibility of paraffin and polyfluoroethylene and the mass flow rates obtained earlier by using a magnetoelectrical measurement method, which confirms the correctness of the results obtained by the new method.

Use of manganin pressure sensors to measure the double-shock compression assures a number of essential advantages as compared with the magnetoelectrical method used earlier [4, 5]. In this case, no application of cumbersome magnets or electrical generators for their supply, nor the amplification of the signals being recorded, will be required. There is no need to measure the magnetic field intensity. This not only simplifies conducting the experiment, but also assures higher measurement accuracy. The new method permits use of a high-explosive charge of arbitrarily large weight, which will afford the possibility of using measuring apparatus possessing the best symmetries and moving forward into higher pressure ranges. Also of no little importance is the fact that the possibility of studying piezoelectric materials, for example, quartzite, was manifest. A comparison between the data in the table characterizing the double-shock compression of quartzite and the data known for the single-shock compression of quartzite [3] shows that the experimental points newly obtained on the $P-\rho$ dependence (Fig. 3) lie substantially to the right of the stipoverite branch of the single-compression curve for quartzite. This indicates the formation of a more compact phase of SiO_2 (approximately by 11-17%) under the compression conditions described, then stipoverite. Such an increase in the density of compounds of the MeX_2 type has been noted in [6, 7] for isotope transformations of substances having a rutile-like structure with the coordination number 6, and in a fluorite-type structure with the coordination number 8. Another indirect confirmation for obtaining a fluorite-like mode of SiO_2 under the multiple dynamical loading conditions is the orthorhombic SiO_2 structure of $\alpha - PbO_2$ type detected in [8]. According to [6] and [9], a fluorite-like structure which is stable at high pressures can be assumed after reduction of the load to the orthorhombic mode of $\alpha - PbO_2$ type. The results obtained in this paper are in good agreement with the conceptions expressed in [6, 9] and the experimental results from [8].

LITERATURE CITED

1. D. Bernstein and D. Keough, "Piezoresistivity of manganin," J. Appl. Phys., 35, 1471 (1964).
2. G. V. Simakov, M. N. Pavlovskii, N. G. Kalashnikov, and R. F. Trunin, "Shock compressibility of twelve minerals," Izv. Akad. Nauk SSSR, Ser. Fizika Zemli, No. 8, 11 (1974).
3. R. F. Trunin, G. V. Simakov, M. A. Podurets, B. N. Moiseev, and L. V. Popov, "Dynamic compressibility of quartzite at high pressures," Izv. Akad. Nauk SSSR, Ser. Fizika Zemli, No. 1, 13 (1971).
4. L. V. Al'tshuler and M. N. Pavlovskii, "Magnetoelectrical method of determining the density behind the front of colliding shocks," Zh. Prikl. Mekhan. i Tekh. Fiz., No. 2 110 (1971).
5. N. G. Kalashnikov, L. V. Kuleshova, and M. N. Pavlovskii, "Shock compression of polytetrafluoroethylene to pressures of ~1.7 Mbar," Zh. Prikl. Mekhan. i Tekh. Fiz., No. 4, 187 (1972).
6. L. F. Vereshchagin, S. S. Kabalkina, and A. A. Komilevets, "Phase transition in MnF_2 at high pressure," Zh. Éksp. i Teor. Fiz., 49, No. 6 (12), 1728 (1965).
7. Syono Akimoto, "High pressure synthesis of fluorite type PbO_2," Met. Res. Bull., 3, 153 (1967).
8. V. N. German, M. A. Podurets, and R. F. Trunin, "Synthesis of a highly compact phase of silicon dioxide in shock waves," Zh. Éksp. i Teor. Fiz., 64, No. 1, 205 (1973).

9. B. G. Hyde, L. A. Bursill, M. O'Keefe, and S. Anderson," Continuous topological variation of coordination in crystals: Structural relations and possible transformation mechanisms," Nature Phys. Sci., 273, No. 72, 35 (1972).