SHOCK COMPRESSION OF POLYTETRAFLUOROETHYLENE TO A PRESSURE OF ~1.7 mbar

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This paper gives the results of an experimental investigation of the single and double shock compressibility of polytetrafluoroethylene (Teflon) and measurements of the velocity of sound behind the shock front.

The single shock compressibility of Teflon was investigated by the reflection method [1]. The velocity of propagation of the shock front in the samples was measured by the electric contact method [2]. In calculation of the compression parameter behind the shock fronts the screen expansion isentropes were identified with the mirror images of the shock adiabats [2]. The dynamic adiabats of copper, iron, and aluminum used in this case were taken from [3, 4]. The density of the investigated Teflon specimens was $\rho_0 = 2.19$ g/cm^3. The experimental results which characterize the single shock compressibility of Teflon are shown in Table 1, which gives the screen material, the mass velocity U_* in it, the wave velocity D and mass velocity U in Teflon, the shock compression pressure P, and the relative compression $\sigma = \rho/\rho_0$. In Fig. 1 (curve 1) the data of Table 1 are compared with the results of similar investigations by other authors [5] (curves 2, 3, and 4 correspond to $\rho_0 = 2.16$, 2.179, and 2.24 g/cm^3). Beginning at U = 1 km/sec the relationship D(U) is practically linear and can be represented by the expression

$$D = 2.18 + 1.58\,U$$

When $U \leq 1$ km/sec, the course of curve D(U) is such (see Fig. 1) that $D_0 = 1.5$ km/sec. This value corresponds exactly with the value of the elastic velocity of sound measured in [6]. Another point that should be noted is the curvature of relationship D(U) of Teflon which is characteristic of organic compounds, and is probably due to the increase in specific heat of the substance with increase in temperature. The absence of appreciable kinks on the shock compressibility curve suggests that no phase transformations occur in the investigated substance.

The shock adiabat of Teflon is represented by an equation of state with limiting density

$$P = \frac{\rho_0 C_0^2}{n(h-\sigma)}\left[\left(h - \frac{n+1}{n-1}\right)\sigma^n + \frac{2n}{n-1}\sigma - (h+1)\right]$$

TABLE 1

Screen material	U_*, km/sec	D, km/sec	U, km/sec	P, kbar	σ
Copper	0.17	2.15	0.30	14	1.162
Copper	0.34	2.70	0.64	38	1.310
Aluminum	1.14	4.46	1.45	142	1.482
Aluminum	1.50	5.16	1.86	210	1.564
Copper	1.76	6.36	2.70	376	1.738
Aluminum	2.70	7.12	3.18	496	1.807
Aluminum	3.70	8.81	4.25	819	1.932
Iron	3.08	9.28	4.42	898	1.910
Iron	4.55	12.35	6.45	1744	2.093

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TABLE 2

Screen material	U_*, km/sec	Compression parameters of Teflon for first shock wave				Compression parameters of Teflon for reflected shock wave			
		D_1, km/sec	U_1, km/sec	P_1, kbar	$\sigma_1 = \rho_1/\rho_0$	D_{12}, km/sec	ΔU, km/sec	P_2, kbar	$\sigma_2 = \rho_2/\rho_0$
Paraffin	2.03	4.55	1.52	151	1.503	7.86 6.80	1.52 0.89	545 349	1.866 1.732

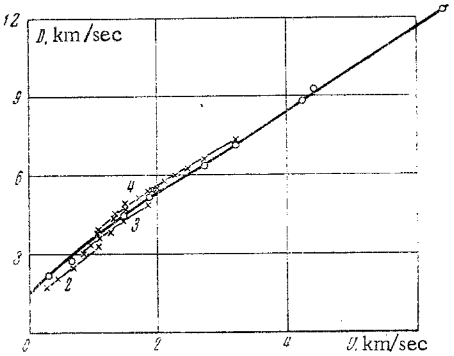

Fig. 1

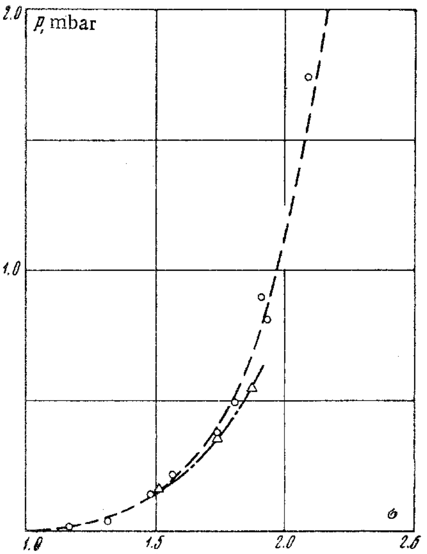

Fig. 2

with the following parameters: initial density of substance $\rho_0 = 2.19$ g/cm^3, initial velocity of sound $C_0 = 1.81$ km/sec, polytropic index $n = 6$, limiting degree of compression $h = 3.4$. The theoretical curve of $P(\sigma)$ with the experimental points is shown by the dashed line in Fig. 2.

We also investigated the double shock compression of Teflon by the magnetoelectric method of determining mass velocities [7]. In the first series of experiments the double compressibility was measured in the case of a head-on collision of plane shock waves by the method described in detail in [8]. The setup of these experiments is shown in Fig. 3a [1) explosive charge; 2) paraffin screen 10 mm thick; 3) Teflon; 4) magnetoelectric pickup loop of 0.1-mm thick aluminum foil with leads to oscillograph]. The thickness L_0 of the Teflon layer enclosed between the crosspieces of the pickup loop was 15 mm. One of the obtained oscillograms is shown in Fig. 4a, where the scale frequency is 5 MHz. As was shown in [8], the small step in the middle of the leading edge of the first surge characterizes the difference in time of approach of the shock waves to the loop from opposite sides. The shoulder in the middle of the trailing edge corresponds to the difference in time of arrival of reflected shock waves at the loop. The amplitude of the pulse on the oscillogram corresponds to twice the mass velocity of motion of the loop crosspiece (2 U_1).

The results of the experiment are presented in the first line of Table 2, which gives the screen material and U_*, the compression parameters of the specimens for the first shock wave, and the compression parameters of the specimens for the second (reflected) shock wave (D_{12} is the velocity of propagation of the reflected wave relative to the moving material, P_2 is the pressure behind the reflected wave front, $\sigma_2 = \rho_2/\rho_0$ is the relative compression).

A modified version of this method was also used in the case where double compression of Teflon specimens 4-5 mm thick was effected (see Fig. 3b) by a shock wave reflected from a screen 5 placed behind the Teflon specimen 3. The screen in this case was copper, which has a greater dynamic rigidity than Teflon. One of the oscillograms of this series of experiments is shown in Fig. 4b. The first surge of the left-hand pulse on the oscillogram corresponds to the moment of arrival of the compression shock wave at the first crosspiece of the pickup loop 4. The amplitude of the left-hand pulse is proportional to the mass velocity U_1 in the compression wave. The flat top of the pulse corresponds to the time t_1 of motion of the shock wave with velocity D_1 through the specimen to the second crosspiece of the loop, so that $D_1 = L_0/t_1$. At this instant the beam on the oscillogram drops to the zero line. The first surge of the right-hand pulse on the oscillogram corresponds to the arrival at the loop of the reflected wave from the copper screen. During the time interval t_2 the reflected wave moves with velocity D_{12} through a specimen previously compressed by the first shock wave ($D_{12} = L_0/\sigma_1 t_2$). The amplitude of the right-hand pulse is proportional to the change in the mass velocity ΔU in the reflected shock front. Thus, the first pulse corresponds to compression of the Teflon by the first compression wave, while the second pulse corresponds to its compression by the second

TABLE 3

Screen material	U_*, km/sec	Compression wave parameters				c, km/sec
		D_1, km/sec	U_1, km/sec	P_1, kbar	σ	
Paraffin	1.41	3.99	1.21	106	1.460	5.3
	2.03	4.55	1.52	151	1.503	5.8

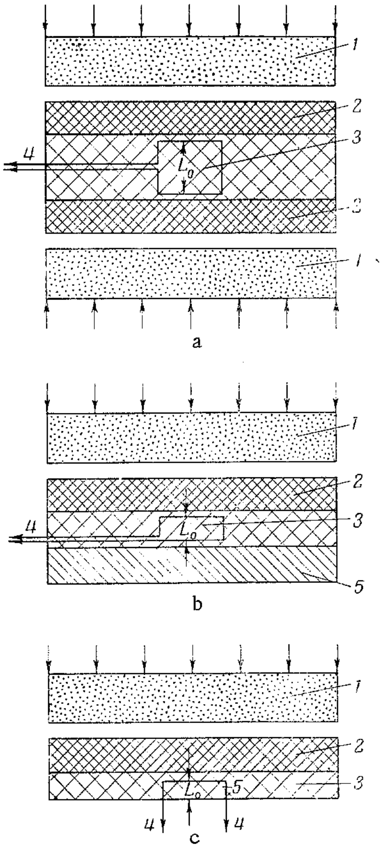

Fig. 3

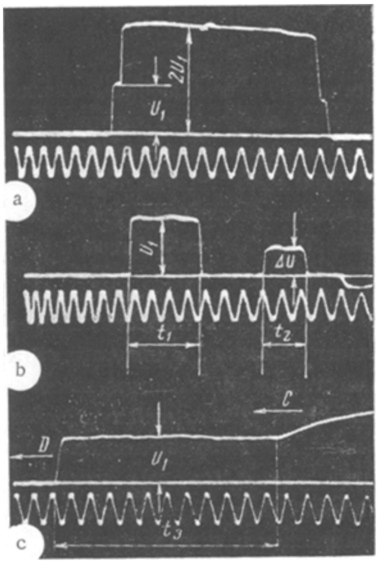

Fig. 4

shock wave reflected from the copper screen. The experimental results are given in the second line of Table 2. The described method provides experimental points characterizing the double compressibility in the intermediate pressure region between the pressure produced by single compression and the pressure attained by head-on collision of the shock waves. The compression parameters of the specimens for the first shock wave in these two series of experiments was determined from the wave velocity D_1, measured in specially conducted experiments, and the well-known relationship D(U) for Teflon (see Fig. 1)

$$P_1 = \rho_0 U_1 D_1, \quad \sigma_1 = D_1 (D_1 - U_1)^{-1}$$

For the case of head-on collision of shock waves the compression parameters of Teflon for the second shock wave were determined in accordance with [8]

$$P_2 = P_1 + \frac{\rho_1\rho_2}{\rho_2 - \rho_1} U_1^2, \qquad D_{12} = \frac{\rho_2}{\rho_2 - \rho_1} U_1$$

The compression parameters of Teflon for the shock wave reflected from the copper screen were calculated by using the following expressions:

$$P_2 = P_1 + \rho_1 \Delta U D_{12}, \quad D_{12} = \frac{\rho_1\rho_2}{\rho_2 - \rho_1} \Delta U, \quad \sigma_2 = \frac{L_0}{L_0 - U_1 t_1 - \Delta U t_2}$$

Here ρ_1 and ρ_2 are the densities behind the first and second shock fronts, respectively; ΔU is the change in velocity of motion of the crosspiece of the magnetoelectric pickup due to the arrival of the reflected shock wave from the copper screen; L_0 is the initial thickness of the specimen; t_1 and t_2 are the times taken by the first and reflected shock waves, respectively, to pass through the specimen (see Fig. 1b).

In Fig. 2 the data of Table 2 are compared with the single-compression shock adiabat. Investigations of the shock compressibility of Teflon were supplemented by observation of the rarefaction waves by the method described in detail in [9, 10]. The setup of these experiments is shown in Fig. 3c [1) explosive charge; 2) paraffin screen; 3) Teflon specimen; 4) Π-shaped aluminum foil pickups with leads to oscillograph, depth of pickup in specimen $L_0 \sim 5$ mm]. One of the obtained oscillograms is shown in Fig. 4c (D is the compression shock wave, C is the centered rarefaction wave). The maximum rarefaction wave velocities determined in this way

$$C = U_1 + \frac{L_0 - U_1 t_3}{t_3 - L_0 / D}$$

are given in Table 3 together with the parameters of the compression wave for Teflon. These velocities of rarefaction waves correspond to an expansion isentrope gradient

$$\left(\frac{\partial P}{\partial \rho}\right)_S = C^2$$

which practically coincides with the gradient of the single-compression shock adiabat.

LITERATURE CITED

1. Ya. B. Zel'dovich and Yu. P. Raizer, Physics of Shock Waves and High-Temperature Hydrodynamic Phenomena [in Russian], Fizmatgiz, Moscow (1963).
2. L. V. Al'tshuler, M. N. Pavlovskii, L. V. Kuleshova, and G. V. Simakov, "An investigation of alkali metal halides at high shock compression pressures and temperatures," Fiz. Tverd. Tela, 5, No. 1 (1963).
3. L. V. Al'tshuler, S. B. Kormer, A. A. Bakanova, and R. F. Trunin, "Equations of state of aluminum, copper, and lead for the high-pressure region," Zh. Éksp. Teor. Fiz., 38, No. 3 (1960).
4. L. V. Al'tshuler, A. A. Bakanova, and R. F. Trunin, "Shock adiabats and zero isotherms of seven metals at high pressures," Zh. Éksp. Teor. Fiz., 42, No. 1 (1962).
5. P. H. Netherwood, M. H. Wagner, W. F. Waldorf, N. A. Loute, D. T. Morgan, M. Rockowitz, and A. L. Atkinson, Compendium of Shock Wave Data, University of California (1966).
6. V. V. Dzenis and V. Ya. Lipovskii, "An investigation of the effect of the geometric dimensions of specimens on the rate of propagation and damping constant of longitudinal vibrations in Teflon," Mekhan. Polim., 4 (1966).
7. L. V. Al'tshuler, "Use of shock waves in high-pressure physics," Usp. Fiz. Nauk, 85, No. 2 (1965).
8. L. V. Al'tshuler and M. N. Pavlovskii, "Magnetoelectric method for determining the density behind the front of colliding shock waves," Zh. Prikl. Mekhan. i Tekh. Fiz., No. 2 (1971).
9. L. V. Al'tshuler and M. N. Pavlovskii, "Investigations of clay and clay shale under heavy dynamic loading," Zh. Prikl. Mekhan. i Tekh. Fiz., No. 1 (1971).
10. L. V. Al'tshuler, M. N. Pavlovskii, and V. P. Drakin, "Features of phase transitions in compression and rarefaction shock waves," Zh. Éksp. Teor. Fiz., 52, No. 2 (1967).