VISCOSITY OF NaCl IN SHOCK COMPRESSION

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This article describes the results for the determination of viscosity for NaCl compressed by a plane shock wave from data on the build-up time and maximum amplitude of the wave at various distances from the specimen face in the pressure range 1.5–90 kbars. Shock waves in NaCl were generated by the impact of 0.5 mm thick aluminum platelates accelerated to velocities (w) of 1650 and 1720 m/sec. The acceleration to 1650 m/sec was produced (with the aid of an explosive charge in the form of 1.0 mm thick strip) by a glancing shock wave. The back pressure of the explosion products behind the striker was several kilobars, while its deviation along a base of 80 mm did not exceed 0.5 mm. The striker traveling at a velocity of 1720 m/sec rebounded from a 5 mm brass screen in which a plane shock wave was generated by the impact. The deviation of this striker on a diameter of 80 mm did not exceed 0.3 mm. NaCl powder specimens (84 mm diameter) compacted to a density $\rho_0 = 1.87$ g/cm^3 (porosity = 1.17) were used. The experiments consisted in recording the mass velocity u in the wave (as a function of time) at distances of 2–25 mm from the collision boundary by an electromagnetic method developed by Zavoiskii. The average values of the maximum mass velocity u_1 and wave build-up time $\Delta\tau$ are reproduced in a table and in Fig. 1, while experimental oscillograms are shown in Fig. 2. The upper oscillogram beam records the mass velocity at a distance x = 5.1 mm ($u_1 \approx 240$ m/sec and $\Delta\tau = 0.55$ μ/sec); the lower beam records at x = 10.2 ($u_1 =$ = 114 m/sec and $\Delta\tau \approx 3.4$ μsec). The presence of a negative phase is associated with distortions produced in protracted measurements due to the design of the probe used at this point. Thus, as the distance travlled by a shock wave increases there is a sharp decrease in u_1($u_1 \simeq$ $\simeq x^{-1.23}$) and an increase in the duration and build-up time of the wave.

Since the pressure in a shock wave (in the dstance interval studied) varies from 90 to 1.5 kbar and considerably exceeds the yield and breaking stresses of NaCl specimens, it was natural to interpret the results obtained by using a liquid model of a solid.

The results of calculations of parameters of a shock wave carried out for the case of an ideal liquid do not describe experimental results (curve 1 in Fig. 1).

It was assumed in these calculations that the increase in entropy at the wave front may be neglected and that the relation between pressure and mass velocity in the entire flow zone in NaCl is the same as the known relation at the wave front [1]

$$p = \rho_0 (\alpha + \beta u) u \,. \tag{1}$$

Parameters $\alpha = 2.54$ km/sec, $\beta = 1.46$ were determined from data on the equation of state for NaCl [2] at $\rho_0 = 1.83$ g/cm^3. In the pressure range in which this substance may be regarded as liquid and in which the phenomena observed cannot be described by the framework of a model for an ideal liquid, it is reasonable to use a model of a viscous liquid for interpreting the experimental results. The influence of heat conduction may be neglected since its contribution to the dissipation of energy is insignificant. The experimental results were analyzed with the aid of a solution (obtained in [3]) for the problem of attenuation in a plane sonic wave generated in a viscous liquid by a pulse applied to the boundary of the substance; hence,

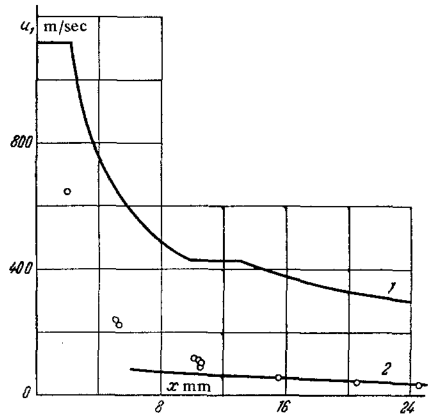

Fig. 1. Maximum mass velocity u_1 plotted against the distance x.

$$u(x, \tau) = \frac{1}{\sqrt{4\pi a x}} \int_0^\infty u_0(\tau') \exp\left(-\frac{(\tau' - \tau)^2}{4ax}\right) d\tau',$$
$$\tau = t - \frac{x}{c}, \quad a = \frac{\eta}{2\rho_0 c^3}, \tag{2}$$

where $u_0(\tau')$ is the time dependence of the mass velocity at the substance boundary, η is impact viscosity including both viscosity coefficients [3], and c = 3.25 km/sec is the sound velocity determined by ultrasonic measurements. In the case of a short initial pulse, which corresponds to the experimental conditions, we have

$$u(x, \tau) = \frac{\exp(-\tau^2/4ax)}{\sqrt{4\pi a x}} \int_0^\infty u_0(\tau')\, d\tau'. \tag{3}$$

The use of the sonic approximation is fully justified for large distances at which $u/c \ll 1$.

Under experimental conditions employed the maximum shock wave corresponds to $\tau \approx 0$. Taking as the start of the wave the moment $\tau = 1.7\sqrt{4ax}$, which corresponds to the minimum measurable deivation of the beam on the oscillogram, we obtain the following expression for the impact viscosity:

$$\eta = \frac{(\Delta\tau)^2 \rho_0 c^3}{5.8x}. \tag{4}$$

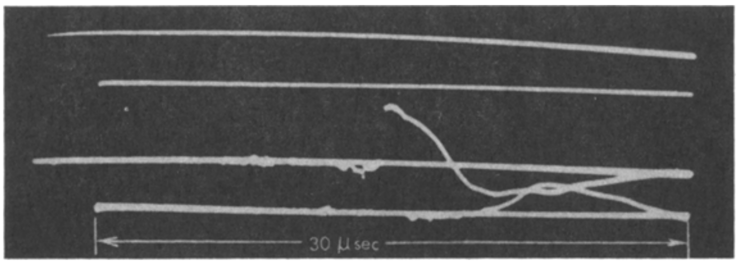

Fig. 2. Experimental oscillogram of a shock wave, scanning teim = 30 μsec.

x, mm	$\Delta\tau$, μsec	u_1, m/sec	p_1, kbar	$\eta_1 \cdot 10^4$, poise	$\eta_1 \cdot 10^4$, poise
		$w = 1650$ m/sec			
0	—	1120	87	—	—
2	0.31	647	42	0.5	1
5.1	0.55	240	13	0.7	3
10.2	3.4	114	5.8	12	7
10.3	3.7	112	5.7	15	7
15.5	4.2	57	2.8	13	18
20.5	5.8	42	2.1	19	25
		$w = 1720$ m/sec			
5.2	0.67	225	12	0.9	4
10.3	3.7	110	5.6	15	8
10.5	4	90	4.5	17	11

Here $\Delta\tau = 1.7\sqrt{4ax}$ is the wave build-up time.

The results of calculation of η_1 and η_2 (from (4) and (3), respectively) at $\tau = 0$ are reproduced in a table. The agreement between η_1 and η_2 improves as the shock wave weakens, which is in accordance with the starting premise of the calculations. Using a different method, other workers [4] obtained for NaCl single crystals at p = 240 kbar a value $\eta = (2 \pm 1)10^5$ Poise and for specimens with a porosity of 1.3 at p = 520 kbar a value $\eta < 10^4$ Poise, which is in agreement with the results produced above. The relation $u_1(x)$ computed from (2) for $\eta = 1.3 \cdot 10^5$ poise (curve 2, Fig. 1) satisfactorily describes the experimental data in the range of large x.

It should be noted that in our calculations the viscosity was assumed constant. This contradicts the experimental results which show that η increases with decreasing pressure. Consequently, η values determined from (2)–(4) represent averages for the pressure range between the initial level (at the impact boundary) and the level at point x for which η was determined.

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