PARAMETERS OF THE SHOCK WAVE PRODUCED BY EXPLODING SHEET CHARGES AT SHORT DISTANCES

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Interest has recently developed in sheet explosives as a means of forming metals [1]. In this connection the authors have investigated the parameters of the shock waves produced by exploding sheet charges in various media.

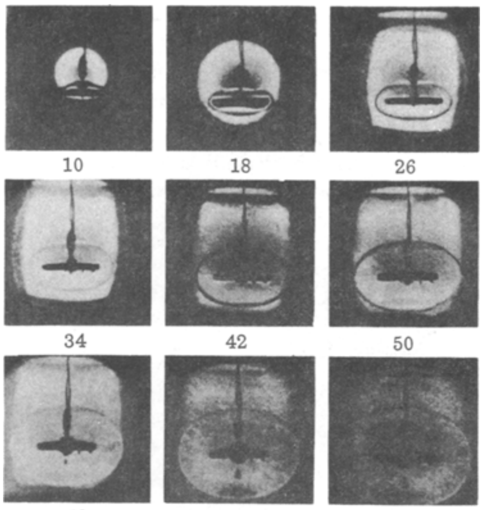

Fig. 1

The experiments were conducted with circular charges of diameter d = 150 mm and thickness δ = 2 mm. These charges, whose properties have already been described in a previous publication [2], detonate with a velocity of 7400 m/sec at density ρ = 1.6 g/cm^3.

The propagation of the shock waves was studied by means of high-speed photography in the continuous and time-magnifier regimes. The explosions were set off in water, air and vacuum.

Shock wave in water. In order to register the shock waves in water we used vessels with transparent plane walls in conjunction with shadow photography. To provide illumination we exploded some of the same explosive placed behind the vessel and initiated at the same time as or slightly before the main charge.

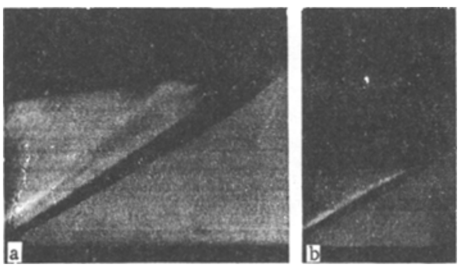

Fig. 2

For the time-magnifier variant Fig. 1 presents frames reflecting the formation of the shock wave (SW) in water. The figures indicate the times (μsec) from the moment of initiation of the charge. The shape of the shock wave in water is an ellipsoid of revolution, which in the course of time becomes a sphere. The time required for this transition is determined by the ratio of the diameter to the height of the charge, and also depends on the properties, primarily the density, of the medium in which the charge is detonated.

Figure 2 shows the propagation in water of the SW from a plane charge photographed in the continuous regime: a) in the direction normal to the plane of the charge, b) in the radial direction.

For the purposes of comparison and wave parameter calculations we also obtained photographs of the propagation of a SW of spherical shape from the explosion of a cylindrical charge of the same weight with d = δ, initiated at the center.

The results of analyzing the photograms are presented in Table 1, where τ' (μsec) is the time from the moment of initiation. τ'' (μsec) is the time from the moment the SW reaches the surface of the charge, R (mm) is the distance traveled by the shock front in time τ'', D* (m/sec) is the velocity of the SW at time τ'' calculated from continuous scanning data and checked against the empirical formulas derived, and p (kg/cm^2), U (m/sec), ρ (g/cm^3), and t° C are, respectively, the pressure, flow velocity, density and temperature in the shock front.

Since the dependence of the distance R traveled by the shock front on time τ in logarithmic coordinates is described by a straight line (Fig. 3), where the points represent: 1) the propagation of the SW from the explosion of a plane charge in the normal direction, 2) the same in the radial direction, 3) the propagation of the SW from the explosion of a cylindrical charge. In general form we have R = $\alpha\tau^n$. Using the experimental data obtained, we will derive empirical relations valid in the range 10–80 μsec,

$$R_1 = 3.80\tau^{0.86}, \qquad R_2 = 2.50\tau^{0.91},$$
$$R_3 = 5.47\tau^{0.77}.$$

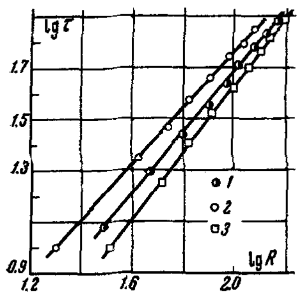

Fig. 3

Differentiation of these equations gives the dependence of the shock wave velocity D* on time

$$D_1{}^* = 3.23\tau^{-0.15}, \quad D_2 = 2.28\tau^{-0.09}$$
$$D_3 = 4.22\tau^{-0.23}.$$

Using Yakovlev's tables [3], from the values of the shock wave velocities we calculated the other parameters (p, U, ρ, t) in water.

On the basis of the data obtained, we derived relations for the change with distance in the pressure at the shock front produced by a plane charge; these relations are valid in the ranges of distances indicated in parentheses: $p = 2.5 \cdot 10^5 R^{-0.99}$ (10 – 160 mm), $p = 8.5 \cdot 10^4 R^{-0.97}$(30 – 120 mm). For a concentrated charge the pressure-distance relation has a more complicated form and for that reason is not presented here.

Table 1

τ', μsec	τ'', μsec	R, mm	D^*, m/sec	p, kg/cm^2	U, m/sec	ρ, g/cm^3	t °C	R/r_0
Plane charge in normal direction								
0	0	0	5 900	161 700	2 590	1.78	710.0	—
1	1	6	4 000	54 170	1 340	1.51	217.0	6
8	8	13	2 400	10 000	450	1.22	56.0	23
12	12	31	2 230	7 800	390	1.19	49.0	31
20	20	46	2 060	5 330	290	1.15	39.0	46
28	28	64	1 960	4 200	250	1.12	35.0	64
36	36	81	1 890	3 440	200	1.11	31.1	81
44	44	94	1 830	2 840	190	1.10	28.5	94
52	52	106	1 790	2 520	170	1.10	27.6	106
60	60	119	1 750	2 230	150	1.08	26.2	119
68	68	133	1 720	2 000	130	1.08	25.8	133
76	76	146	1 680	1 730	120	1.07	24.7	146
80	80	155	1 670	1 600	110	1.06	24.4	155
Same in radial direction								
10	0	0	5 870	159 600	2 570	1.77	701.0	—
12	2	7	3 800	46 670	1 220	1.48	188.0	0.09
16	6	15	2 540	12 690	520	1.25	63.8	0.20
20	10	20	1 850	3 000	200	1.10	28.8	0.27
28	18	35	1 750	2 233	150	1.08	26.2	0.47
36	26	49	1 720	2 000	130	1.07	25.8	0.65
44	34	60	1 660	1 533	100	1.06	24.3	0.80
52	42	73	1 630	1 320	90	1.05	23.9	0.91
60	50	87	1 600	1 080	70	1.04	23.6	1.16
68	58	99	1 580	930	60	1.04	23.3	1.32
76	66	111	1 570	870	60	1.04	23.1	1.48
80	70	116	1 560	800	60	1.04	23.0	1.55
Concentrated charge								
2	0	0	5 900	161 700	2 590	1.78	710.0	—
4	2	7	3 600	40 000	1 100	1.45	156.0	0.40
8	6	22	2 800	18 890	660	1.28	84.0	1.26
16	14	41	2 300	9 000	420	1.21	52.0	2.34
24	22	59	2 070	5 500	300	1.15	40.0	3.37
32	30	73	1 930	3 890	240	1.12	29.4	4.17
40	38	90	1 820	2 760	180	1.09	28.3	5.15
48	46	103	1 750	2 230	150	1.08	26.2	5.90
56	54	117	1 690	1 830	120	1.07	24.9	6.68
64	62	130	1 630	1 320	90	1.06	23.6	7.44
72	70	143	1 580	930	60	1.04	23.0	8.17
80	78	155	1 540	600	40	1.03	22.6	8.85

Table 2

l, mm	D^*, m/sec	p, kg/cm^2	V, m/sec
0	8 000	670	11 400
10	7 500	600	10 500
20	6 900	500	9 500
30	6 400	430	8 800
40	6 000	370	7 700

From the results obtained it follows that in the first stage at $R \leq \leq 50$ mm a sharp fall in the shock wave parameters with distance is observed for a plane charge in the radial direction and a less rapid fall for the same charge in the normal direction.

If this relation is expressed in terms of the reduced distance R/r_0, then the above-mentioned qualitative dependence is somewhat modified, namely, attenuation of the parameters in the radial direction proceeds at very small, and in the normal direction at very large relative distances. Here, for a plane charge in the normal direction it is assumed that $r_0 = 0.5\delta = 1$ mm and in the radial direction $r_0 = 0.5d = 75$ mm, while for a concentrated charge $r_0 = 0.5d = 17.5$ mm.

Shock wave in air and vacuum. The measurements were made at distances from the charge (at $R < 10 - 15\, r_0$), at which the shock wave is still undetached from the leading front of the expanding explosion products (EP) [4]. The pressure-chamber experiments were conducted at a residual pressure of 5–10 mm Hg. The profile of the shock wave from a sheet charge, previously described in [2], is little different from the profile of a wave formed in vacuum or water.

There is a difference only in the time taken for the ellipsoid to become a sphere; this is shortest in a vacuum and longest in water.

In Table 2 we present the dependence on distance l of the shock wave velocity D^* and pressure p in air and of the velocity V of expansion of the EP in vacuum.

From the velocity values and the tabulated data for air [3] it is possible to calculate the other shock wave parameters.

The results obtained may prove useful for engineering calculations.

In conclusion, the authors thank E. D. Fedin for help in setting up the experiments.

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