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The Study of Large Plastic Deformation and Fracture of Plates by Blast of Explosives in the Tubes

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Abstract Experimental studies and calculations of large plastic deformations and fracture of the aluminum alloy plates of different thickness by the shock waves of blasts of powerful explosives in tubes of different lengths and diameters were carried out. The deformations the plates were investigated with a single and consistent impact loading by shock waves. Parameters of shock waves and loads on the plates in the tubes were measured and method of their calculation was worked. The empirical dependences of the maximum residual deflections and increment area of the plates depending on the load pulse parameters and the plates were obtained. Dynamic strength of the aluminum alloy was defined.

Keywords Plate, Explosive, Blast, Tube, Shock Wave, Test, High-Speed Photo, Calculation, Technical Applications, Plastic Deformations, Fracture

1. Introduction

An ability to concentrate and direct the action of the blast shock wave in tubes is used in oil and gas wells, tunneling, in rocket engines, modeling of natural and technological dynamic processes an explosive type, including blasts of fuel in transport tunnels. The blast stamping of plates is used in the engineering works. Due to increased efficiency of operation the blasts in tubes makes it possible to abandon the blast basins and chambers, to simplify the manufacturing.

However, these applications usually used brisance action of contacting blasts [1, 2]. An approximate theory of explosives blast in tubes with gas when the gas mass was smaller than the mass of explosion products m the results of measurements of shock waves parameters inside tubes with air at the blasts of powerful explosives at their open end are given in [3, 4]. The discrepancy between the calculated and measured parameters of explosion shock wave was less than 10%, when the gas mass was smaller than the mass of explosion products. The study of the dynamic behavior of materials was carried in [5].

Below are given results of measurements and calculations of large plastic deformations and fracture of the aluminum alloy plates of different thickness by the shock waves of blasts of powerful explosives in tubes of different lengths and diameters. The deformations the plates were investigated with a single and consistent impact loading. Parameters of shock waves and loads on the plates in the tubes were measured and method of their calculation was worked. The empirical dependences of the maximum residual deflections and increment area of the plates depending on the load pulse parameters and the plates were obtained. Dynamic strength of the aluminum alloy was defined. Blasts of explosives in the tubes were made for improved the methods blast stamping, determining the dynamic strength of metals and alloys, development of methods for simulating the dynamic processes of explosive type in science and technology.

2. Statement of the Tests

Under the study of large plastic deformation and fracture of plates the blasts took place in the center of the inlet section of steel tubes of length L = 1,0 and 0,5 m, radius r = 0,075 and 0.046 m, area of the cross section tubes S_t = 0,0177 and 0,00664 m^2. Plastic explosive charges had a heat of blast Q = 4,8 MJ/kg, a density of about 1600 kg/m^3, mass m = (1-16) 10^{-3} kg. Plates of duralumin D16 with yield point σ_0 = 380 MPa, thickness Δ near 0,60, 0,91 and 1,87 mm clamped in a holder with an inner diameter of 200 mm, ensuring against the drawing. The entire assembly with a plate was suspended on a pendulum at end of the tube opposite blast. Ratio of the area S_t of the blast action in the tubes to the area S of the plates was S_t/S = 0,56 and 0,21. The impulse of load I range up to 40 Ns determined by the deviation of the pendulum. After the blasts the maximum residual deflection δ at the center of the plates, their profile and increase in the area ΔS were measured. Additionally the increment of the maximum pressure ΔP_m reflected shock wave was measured, as shown in figure 1a, by face piezoelectric sensor in the center of the plates thickness of 3,74 mm on the pendulum. Pressure-time in the reflected shock wave in the tube was nearly exponential. Sensitive elements sensors were from quartz or various piezoelectrics. Calibration of the sensors carried out on the press or blast in the blast chamber. Different recording equipment with a frequency band up to 10 MHz was applied.

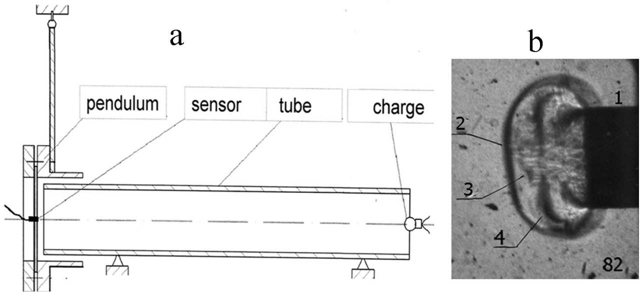

Figure 1. a, b. a - the experimental setup. b - photo a shock wave flowing out from the tube. 1 - tube, 2 - front of shock wave, 3 - contact boundary between the air in shock wave and explosion products, 4 - area of mixed products and hot air behind shock wave.

In some experiments deflection at the center of the plates were measured by electro - contact method and according to the data of high-speed photography. Was used industrial camera SFR-2M with frequency of shooting up to 2.5 10^6 frames/s or in the version streak camera with resolution up to 2 10^{-8} s. A typical picture of the strong shock wave flowing from a tube is shown on figure 1b. Equipment complex applied to measure the actions of blasts in different environments is outlined in [2, 4, 6]. Error of a single measurement by different methods did not exceed 10%.

3. Results of Tests

The results of experiments with a single loading by shock waves in tubes are given in tables 1, 2 and figures 2, 3, where introduced the following notation for parameters of loads and plates: I – impulse of reflected shock waves in tubes determined from the pendulum deviation in Ns, I/m - relative impulse, (m - mass of explosive charge,) in m/s, J = I/S_t - specific impulse in Pas, ΔP_m – overpressure of reflected shock wave measured on pendulum by piezoelectric sensor in tubes, mQ – explosive energy in kJ. Parameters plates have notations: E - Young's modulus in MPa, δ and Δ - deflection and thickness of plates in mm, υ - Poisson coefficient, σ_0 - yield point in MPa.

Table 1. The results measuring of the parameters shock waves and the deformation of plates in the single blasts in the tube 1 m of long.

m 103, kg	mQ, kJ	I, Ns	I, m/s	J, Pas	ΔPm, MPa	Δ, mm	δ, mm	ΔS/S, %
L = 1 m, r = 0,075 m, S_t = 0,0177 m^2								
5,0	24,0	11,3	2260	640	4,8	0,91	15	2,25
5,5	26,4	14,4	2606	810	5,2	0,9	23,2	5,04
7,0	33,6	14,9	2123	840	5,9	0,91	25	5,93
8,5	40,8	21,2	2492	1200	7,8	0,91	33,3	9,57
9,9	47,5	23	2320	1300	8,8	0,91	34,3	9,82
11,0	52,8	24,8	2262	1400	10	0,91	37	12
11,0	52,8	23,8	2171	1400	10	0,91	37	12
11,1	53,3	25,6	2316	1500	10	0,91	36,7	11,7
13,5	64,8	29	2147	1600	4,8	0,91	41	15,3
15,8	75,8	33	2090	1900	12	0,92	45,3	19
15,6	74,9	32,8	2101	1900	14,5	0,92	45	18,3
6,0	28,8	17,6	2933	1000	14,2	1,87	12,5	1,7
8,5	40,8	23,9	2809	1350	5,5	1,86	15	2,23
11,0	52,8	29,9	2727	1680	7,7	1,86	18	3,3
13,5	64,8	34,2	2532	1940	10	1,85	23,8	4,7
15,9	76,3	35	2204	2000	12	1,87	23,4	4,97
15,9	76,3	37,8	2381	2140	13,8	1,87	24,8	5,54

Table 2. The results measuring of the parameters shock waves and the deformation of plates at the single blasts in the tubes 0.5 m of long.

m 10^3, kg	mQ, kJ	I, Ns	I, m/s	J, Pas	ΔP_m, MPa	Δ, mm	δ, mm	$\Delta S/S$, %
L = 0,5 m, r = 0,046 m, S_t = 0,00664 m^2								
0,7	3,36	1,5	2138	230	7,5	0,84	3,5	0,12
5,5	26,4	13,7	2495	2100	28,0	0,92	37,7	10,0
8,1	33,6	17,7	2189	2700	40,0	0,92	39,0	11,9
11,0	40,8	24,5	2207	3788	62,0	0,91	Plates are damaged on the edge	
13,4	47,5	28,5	2127	4337	79,5	0,91		
5,9	52,8	14,0	2375	2100	30,0	1,86	18,8	2,55
8,1	52,8	17,0	2102	2600	43,0	1,86	20,3	3,7
11,0	53,3	24,5	2234	3700	62,0	1,88	26,7	5,7
13,7	64,8	29,0	2119	4400	80,0	1,87	32,8	8,0
15,3	75,8	33,	2162	5000	90,0	1,88	34,0	8,7

Table 3 shows the two sets of experiments obtained at multiple sequential loading plates with thickness of 0,6 mm, and their comparison with the data for a single loading plate's momentum equal to the sum of successive pulses. The measured time dependences of the pressures reflected from plates of shock waves is close to the exponential. The deflection and increment area of plates increased with decreasing tube diameter and thickness of plates for a given momentum in tests. Destruction of 0,91 mm thick plates was obtained at the blasts in a tube radius of 0,046 m at I = 18 Hs, $\delta > 40$ mm, $\Delta S/S > 12$ %. The destruction of the plates were occurred at the place entrapment plate by holder. The typical value of the measured maximal and residual deflections plates in one of the experiments were 48 and46 mm.

Table 3. The comparison of deflection the plates by single the blasts to deflection plates in series from 3 and 2 the successive blasts about the total mass.

m 10^3, kg	mQ, kJ	I, Ns	δ, mm	Notes
L = 0,5 m, r = 0,046 m, S_t = 0,00664 m^2, Δ = 0,6 mm				
8,737	41,9	1,62	47,4	The action of the total momentum
3,1	14,7	0,56	20,4	1 loading
3,1	14,7	0,56	2,4	2 loading
2,88	13,8	0,51	0,8	3 loading
9,35	44,0	1,74	46,5	The action of the total momentum
3,06	14,7	0,52	20,3	1 loading
6,73	32,3	1,3	11,	2 loading

4. Discussion

Experiments of tables 1 and 2 had shown that at single loading the maximum residual deflection δ and the increase in the area of plate ΔS for a given impulse I of shock wave in tube were increased with decreasing radius tubes r and thickness plates Δ. With tube radius r = 46 mm the plates of thickness $\Delta = 0,91$ mm were destroyed on clamped edge at $\delta >$ 40mm, $\Delta S/S = 12\%$, I = 18 Ns. At r = 75 mm destruction of plates did not happen even at maximum load and strain parameters I = 33 Ns, J = 1900 Pas, δ= 45 mm, $\Delta S/S = 12\%$. At given r and Δ deflection δ was proportional to the total impulse of the applied load.

We neglected the contribution of the elastic strain in compiling calculation models. The typical values of the maximum δ_m and residual δ deflections were close. At the blast of the charge weight 0,015 kg at the entrance to tube length L = 1 m these values were the following: $\delta_m = 48$ and $\delta = 46$ mm. Relationship between the maximum stress σ_m and deflection δ_m in the center of the stretched elastic circular plate is determined by the expression [5].

$$(\delta_m/\Delta)(1+0,49\ (\delta_m/\Delta)^2) = \sigma_m r^2 \Delta/48D \qquad (1)$$

Where σ_m - maximum elastic stress, $D = E\Delta^3/12(1-\upsilon^3)$, E - Young's modulus, υ - Poisson coefficient. Assuming $\sigma_m = \sigma_0$ of yield strength duralumin, we find that the maximum elastic deflection σ_m at $\Delta = 0,91$ and 1.87 mm is close to the plate thickness Δ, and the residual deflection δ an order of magnitude greater. This good agrees with experimental data.

Effect of concentration of the blast load on the residual deflection was investigated. It was assumed that only a portion of the plate area πr^2 is accelerated, and its kinetic energy is expended on the work of plastic deformation of the entire plate. This is true when the loading time is much shorter than the time bending. Use the equation of motion a plate in the form (2)

$$d^2x/dt^2 + 4\sigma_0 x/\rho r^2 = F(t)/\pi r^2 \rho\Delta \qquad (2)$$

where ρ – density of plate. Designate $\omega^2 = 4\sigma_0/\rho r^2$, $\mu = \rho\Delta\pi r^2$, $\delta = x_m$. At F = const, $\omega\tau < \pi/2$, we have

$$\delta = I/\mu\omega = I/\pi r\Delta(4\sigma_0\rho)^{0,5} \quad (3)$$

Assuming a spherical shape of the loaded plate and $\delta/R << 1$, to get $\Delta S = \pi\delta^2$. Hence for

$$\Delta S/S = \delta^2/R^2,\ (\Delta S/S)\Delta^2 r^2 = I^2/4\pi^2 R^2\rho\sigma_0 \quad (4)$$

Fig. 2 shows both the dependences δ = F (I/rΔ) (3) calculated for different σ_0 = 380 and 1000 MPa and their comparison with experimental data. The experimental data are lie on linear dependence of $\delta = I/r\Delta(4\pi^2\rho\sigma_0)^{1/2}$ with a value of σ_0 = 1000 MPa in the limits of experimental error. Therefore σ_0 = 1000 MPa can be interpreted as the dynamic yield stress. The dotted line is calculated with σ_0 = 380 MPa equal to the static yield strength.

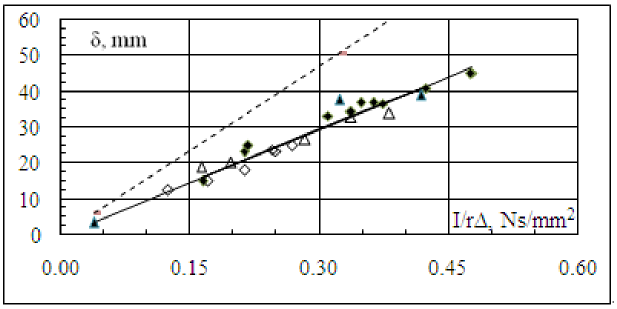

Figure 2. Dependences δ = F(I/rΔ). Experimental data: solid markers Δ = 0,91 mm, transparency markers Δ = 1,87 mm, rhombs - L = 1 m, triangles - L = 0,5 m. Calculations: dotted line - σ_0 = 380 MPa, solid line - σ_0 = 1000 MPa.

Fig. 3 shows the dependence ΔS/S as function of $(I/r\Delta)^2$ (4) calculated by the proposed model with σ_0 = 1000 MPa and its comparison with experimental data. Results of calculations are compared with experimental data for not very large deformations.

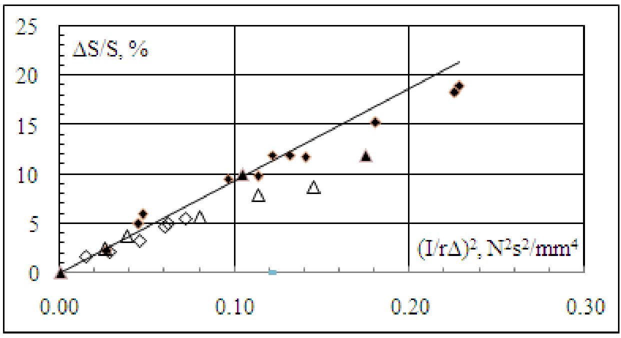

Figure 3. Dependence $\Delta S/S = F(I/r\Delta)^2$. Experimental data: solid markers Δ = 0,91 mm, transparency markers Δ = 1,87 mm, rhombs- L = 1 m, triangles - L = 0,5 m. Solid line - calculation with σ_0 = 1000 MPa,

Table 3 shows the experiments obtained at multiple sequential loading plates and their comparison with the data for a single loading plate's momentum equal to the sum of successive pulses. In first series tests the total deflection δ_t = 23,6 mm after 3 consecutive loadings total momentum I = 1,63 Ns is almost half that for a single loading pulse I = 1,62 Ns, when deflection δ = 47,4 mm on another plate. In second series of experiments on two consecutive loadings with the total momentum I = 1.82 Ns of deflection δ = 31.3 mm was significantly lower than the δ_t = 46.5 mm single exposure with momentum I = 1.74 Ns. This is due to the increase the work of elastic deformation with increasing initial deflection the plates caused by their preceding loading.

5. Summary

The results of studies of large plastic deformation and fracture of plates of different thickness of aluminum alloy under loading the shock waves the blasts of powerful explosive charges in tubes of different lengths and diameters are presented. The experiments were performed with a single and consecutive of momentum loading the plates. The parameters of the shock wave and the loads on plates in tubes were measured and methods of their calculation were developed. Based on the proposed models the empirical dependences of the maximum residual deflection and the change of plate area from the impulse of load were derived. Comparison of calculations and experiments was carried out. Dynamic strength of the alloy was defined. It is shown that the successive loads of the plate by series of pulses load are less efficient than a total momentum load.

Blasts of explosives in the tubes were made for improved the methods blast stamping and determining the dynamic strength of metals and alloys. Studies have shown that the blasts in the tubes can improve the technology of blasting to get rid of the expensive equipment and explosive cameras**.**

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Designations

L, r – length and radius of tubes in m.

$S_t = \pi r^2$ - area of cross section of tube in m^2.

σ_0 = 380 MПa yield point. thickness

Δ - thickness of plate in mm.

ρ – density in kg/m^3.

S_t/S - ratio of the area of the blast action in the tubes to the area of the plates.

δ – deflection in mm.

ΔS - residual increase the area of plates after blast in m^2.

Y - Poisson coefficient.

σ_m - maximum elastic stress in MPa.

E - Young's modulus in Pa,

Q - heat of blast in MJ/kg.

m – explosive mass in kg.

$D = E\Delta 3/12(1- \upsilon^3)$.

E - Young's modulus in MPa.

I – impulse of load determined by the deviation of the pendulum in Ns.

J - I/S_t – specific impulse in Pas.

ΔP_m - maximum pressure (overpressure) of reflected shock wave in MPa.

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