CUMULATION OF SHOCK WAVES IN LAMELLAR MEDIA

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Cumulation of energy of a shock wave moving through a set of alternating layers of materials of high and low density is investigated experimentally. For systems consisting of alternating layers of lead and Plexiglas, it is established that the shock wave pressure p is proportional to $1/x^n$, where x is the distance from the edge of the lamellar system and n is the cumulation index. For the system described, n = 0.42. The relief angle in the lead-Plexiglas lamellar system is ~50°.

PERIODIC structures which cumulate shock wave energy were proposed by Zababakhin.[1] As an example, he considered a plane system of alternating layers of heavy ρ_h and light ρ_l ideal gases with a density ratio $\rho_h/\rho_l = 25$, the geometry of which was such that the ratio ϵ of the thickness of each heavy and light layer to the distance from some point, called the "edge," remained constant; for the heavy layers, this quantity was $\epsilon_h = 0.1$ and for the light, $\epsilon_l = 0.2$. Calculation showed that as one approaches the "edge," unlimited cumulation is observed. The pressure p at similar points (for example, on the inner surfaces of the heavy layers relative to the "edge,"), increases according to the law $p \propto 1/x^n$, where x is the distance from the "edge," and n the cumulation index. Calculation gave the value n = 0.23.

Our problem included an experimental confirmation of the cumulation effect in the systems considered in[1]. The system chosen for the investigation consisted of a set of alternating disks of lead and Plexiglas, the thicknesses of which obeyed the self-similarity law $\epsilon_h = 0.1$, $\epsilon_l = 0.2$. The scheme of the lamellar system is shown in Fig. 1. The nominal thicknesses of the layers (in millimeters) are given below:

i:	1	2	3	4	5	6	7	8	9	10
T_i (lead):	4.00	2.90	2.10	1.50	1.04	0.74	0.57	0.40	0.30	0.21
Λ_i (Plexiglas):	7.20	5.20	3.70	2.70	1.96	1.39	1.00	0.70	0.52	

The actual thicknesses of the layers were less than the nominal values by 0.02—0.04 mm. The diameter of the disks in the experiments amounted to 240—250 mm, which was determined by the necessity of eliminating edge effects on the region of measurement. On the side of the greater thickness of layer T_1, the "stack" bordered on a charge of explosive material (EM), which was a mixture of 50% TNT and 50% hexogene. A plane detonation wave was formed in the charge of explosive material by a special apparatus. Upon firing of the system, a shock wave propagated in the stack in the direction from greater to lesser layer thickness. The number of layers in the experiments was varied from one to 19, and the stack always began with the lead layer T_1; the final layer was also lead, the thickness of which varied depending on the number of the layers in the stack, as given in the table. The measuring apparatus was located at the side of the last lead layer.

In the experiments, the flight velocity of a plate of aluminum foil of thickness 0.05 mm was measured by an electrocontact method.[2] This plate was attached by vaseline to the last lead layer. Specially arranged experiments showed that the aluminum foil of thickness 0.05 mm traveled steadily and was not overtaken by the layer of lead in a distance equal to the base line of the flight (~5 mm) when the stack was spread apart. From the measured flight velocity of the aluminum membrane, the (p, u) diagram made it possible to determine the pressure p and the mass velocity u in the shock wave up

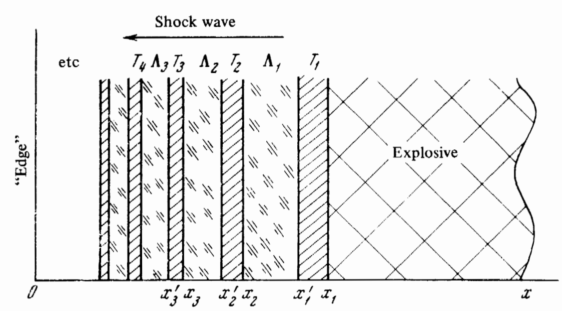

FIG. 1. Scheme of lamellar structure, T_i —layer of lead, Λ_i —layer of Plexiglas, i = 1, 2, 3, . . .; $\epsilon_h = (x_i - x_i')/x_i = 0.1$; $\epsilon_l = (x_i - x_{i+1})/x_i' = 0.2$; ϵ_h —relative thickness of layers of lead; ϵ_l —relative thickness of layers of Plexiglas.

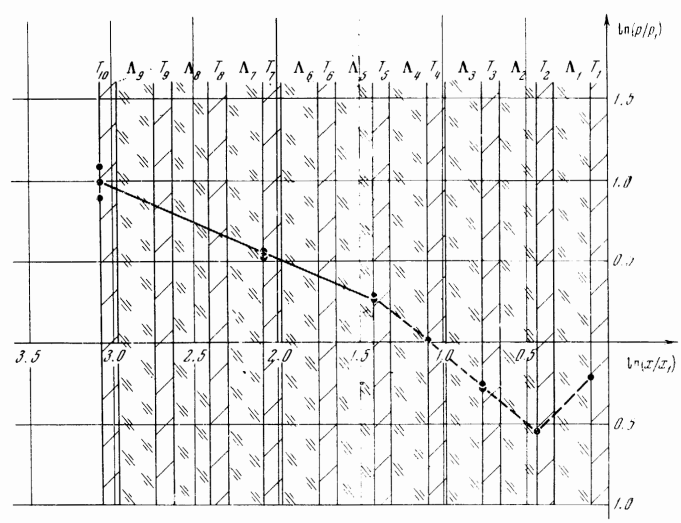

FIG. 2. Dependence of the ratio of pressure at the shock front p to the pressure p_1 at the shock on the boundary between the lead and the explosion products ($p_1 = 0.414 \times 10^{-2}$ bar) on the quantity x/x_i, where x is the distance from the edge, x_1 = 40 mm.

to dissipation of the disturbance on the external boundary of the last lead layer. The equations of state of lead and aluminum were taken from[3].

The measurement results are shown in Fig. 2, where the abscissas represent the ratio of the measured pressure p to the pressure p_1 developed in the shock wave on the boundary between explosion product and the lead ($p_1 = 0.414 \times 10^{12}$ bar) and the ordinates the ratio of the distance from the "edge" of the surface x on which the measurements were carried out to $x_1 = 40$ mm. The graph is constructed in logarithmic coordinates. It follows from the graph that in the lamellar system, which consisted of the lead and the Plexiglas with $\epsilon_h = 0.1$, $\epsilon_l = 0.2$, beginning with the fifth lead layer, the pressure at the front of the shock wave is described by the dependence $p \propto 1/x^n$, where $n = 0.42 \pm 0.07$. The fall in pressure in the first layers of the lamellar structure is associated with the closeness of the boundary of the explosion products.

Thus the effect of cumulation of shock waves in lamellar structures[1] is confirmed experimentally. The lamellar structure of 10 lead and 9 Plexiglas layers with $\epsilon_h = 0.1$ and $\epsilon_l = 0.2$, respectively, allowed us to increase the pressure at the shock front by a factor ~ 2.7.

Edge effects were studied in the lamellar structure. Measurements carried out by the method described in[4] showed that the relief angle in the lamellar system of lead and organic glass with $\epsilon_h = 0.1$ and $\epsilon_l = 0.2$ is much greater than the relief angle in each material of the stack layers, and amounts to $\sim 50°$.

In conclusion, we note that the first experiments which confirm the phenomenon of cumulation in lamellar systems were carried out by K. K. Krupnikov (private communication).

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