DEVELOPING DETERMINANT PERTURBATIONS IN COLLAPSING SHELLS

A. G. Ivanov, Yu. D. Lavrovskii,*
and V. A. Ogorodnikov

UDC 539.374,534.1

Metal cylindrical shells [liners], which are explosively accelerated to velocities of several kilometers per second, are often used in explosive generators to compress a deuteron plasma, for obtaining high dynamic pressures, etc. [1]. In these generators, some set of points around the outer surface of the cylindrical explosive charge is usually detonated simultaneously by one initiating system or another. This leads to the formation of a perturbed detonation front which goes out to the accelerated cylindrical shells, which in turn causes initial prescribed perturbations on their inner surfaces [2]. Problems arise on the behavior of such perturbations as the shell converges to its center, including those related to the effect of the physicomechanical characteristics of the shell material.

The existing linear theories on this phenomenon gives solution, from which it is concluded that the perturbations on the inner surface of the collapsing shell are oscillatory in nature [3]. However, they are based on a series of simplifying assumptions, which as a rule are not valid for many cases of practical interest. Thus, for relatively thin-walled shells accelerated via explosive energy, applying these theories is more than controversial, and today such problems evidently can only be solved numerically. This approach is used, for example, to describe the development of specific perturbations on the outer or inner boundaries of a collapsing spherical shell, with and without considering its material strength [4].

Here pulsed x-radiography is used to investigate the behavior of perturbations on the inner surface of collapsing cylindrical shells which are accelerated via explosive energy. A cross-sectional diagram of the experimental setup is shown in Fig. 1. The detonation on the outer surface of the cylindrical explosive charge, which has a density $\rho_0 = 1.72$ g/cm^2 and a detonation velocity $D = 8.15$ km/sec, is excited at points located at the corners of squares 22 mm on a side, which corresponds to locating 42 points around the circumference. Outer shells of aluminum alloy V95 and steel St.3, and a subshell of St.3 or S1 lead were used in all tests. Perturbations were investigated on the inner surface of the subshell. These materials, with notably different physicomechanical properties, were used to clarify how the strength of the shell material affects the development of perturbations.

X-rays of the shapes of the inner shell boundary in the tests were taken at moments in time which correspond to the shell collapsing to a radius of 0.5 R_+, 0.3 R_+, 0.2 R_+, 0.1 R_+, and ~0.07 R_+, where R_+ is the outer radius of the explosive charge.

A special test was conducted, in which the x-rays were made perpendicular to the shell axis, in order to assure that end unloading did not affect the shape of the collapsing shell in the axial direction. It was shown that when the inner shell boundary collapsed to a radius of 0.1 R_+, the length of the shell section not affected by unloading was 100 mm, which is completely sufficient to obtain objective information of the phenomenon being investigated. Figures 2 and 3 show a montage of x-ray photographs for the steel and lead shells, respectively (the dashed curves are the initial position of the inner shell boundary; the radial dashed lines are the projected direction of points of the detonation perturbation from the outer surface of the explosive charge to the center of symmetry of the shells; the numbers below are the experiment numbers). The results of processing the test x-rays are shown in Table 1. Here t is the time from the start of motion of the inner shell boundary to the time t_i when the x-rays were taken; $r_i = R_i/R_+$ is the relative radius of the inner shell boundary at time t_i; a is the amplitude of the perturbations; δ and λ are the shell thickness and the wavelength of the perturbations at the current radius of the inner shell boundary R_i.

Analysis of the results of test with steel and lead shells shows that the leading perturbations on the inner shell boundary in both cases are formed under projections of the pertur-

---

*Deceased.

Arzamas. Translated from Prikladnaya Mekhanika i Tekhnicheskaya Fizika, No. 5, pp. 116-119, September-October, 1992. Original article submitted June 18, 1991; revision submitted August 16, 1991.

0021-8944/92/3305- 0723$12.50

TABLE 1

Shell material	Test No.	t, μsec	r_i	a	δ	λ
				mm		
Steel	1	6,15	0,53	1—2	1,6	12
	2	17,90	0,32	3—4	2,6	7
	3	23,80	0,21	3—4	3,9	5
	4	26,00	0,11	—	6,5	—
	5	28,10	0,06	—	9,4	—
Lead	7	6,23	0,49	3—4	1,2	12
	8	17,90	0,30	5—6	1,9	7
	9	23,18	0,20	5—6	2,9	5
	10	27,30	0,09	5—6	5,4	3
	11	28,05	0,08	5—7	5,8	3

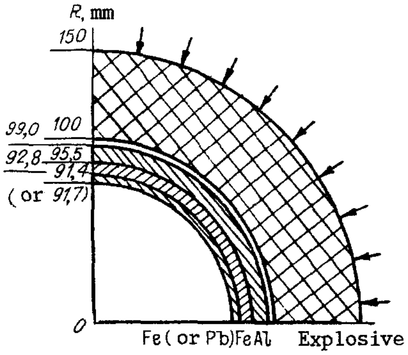

Fig. 1

bation points of the denotation in the explosive charge at the stage shere the shells are accelerated by the explosion products.* At the same stage of shell motion, the perturbation amplitude practically stops growing. In the inertial section of the shell motion ($r_i \le 0.3 \times R_+$), the perturbation amplitude is maintained for a steel shell to a radius of $\sim 0.2\ R_+$, but for a lead shell to $\sim 0.1\ R_+$, and we have the approximate relationship $a \simeq$ const. For a steel shell at a radius $r_i \le 0.2\ R_+$, the perturbations practically run together due to the stretching of its surface and form a region of reduced density of thickness ~a ahead of the basic part of the collapsing shell. For a lead shell this is not observed due to the jetlike nature of the perturbations. The jets start to interact at a radius $r_i \le 0.08\ R_+$ and separate particles of the material reach the center of symmetry of the shell. As the lead and steel shells collapse, it should be noted that the sign of the perturbations are maintained in both the acceleration by the explosion products and in the inertial part of the motion; that is, the oscillatory character of the perturbations is not observed. This fact confirms experimentally that it is incorrect to use linear theory for the motion under investigation.

The physicomechanical properties of the shell material has a significant effect on the shape and amplitude of the perturbations. Thus, while the perturbations have the shape of regular, almost sinusoidal protrusions for the stronger steel shell, the shape of the perturbations in a lead shell, which has practically no strength, is transformed due to the flow in the shock wave: the perturbations stretch out into a jet, which points to a clear nonlinearity of the process. Moreover, the amplitude of the perturbations for steel shells is 1.5 times less than for lead shells.

Estimates of velocity gradients between shell regions in the perturbation zone and between perturbations, taken from test results in the region where the shell is accelerated by explosion products ($r_i = 0.5\text{-}0.3\ R_+$), give accelerations of the perturbed region relative to the unperturbed regions of $dW/dt = 1.4 \cdot 10^9$ cm/sec^2 in a steel shell and $1.1 \cdot 10^9$ cm/sec^2 for a lead shell. The corresponding values of the inertial forces $\sigma_F = \rho_0 \delta dW/dt$ are 0.22 and 0.19 GPa, respectively. The values of the dynamic yield limit of the shell material under these strain conditions ($\dot{\varepsilon} = W/R = 10^4\text{-}10^5\ \text{sec}^{-1}$) are σ_S = 1 GPa for steel [5] and 0.06 GPa

---

*We note that when single-layer plates and shells are accelerated, these perturbations form at the four points (the center of the square, which is formed by the four neighboring points of the perturtabion of the detonation in the explosive charge) [2].

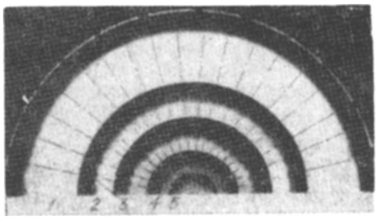

Fig. 2

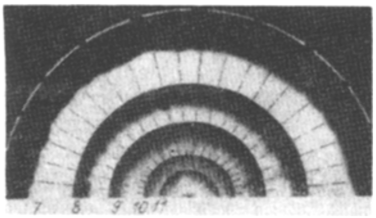

Fig. 3

for lead [6]. A comparison shows that for steel $\sigma_S > \sigma_F$; therefore the shear strength of the shell material has a stabilizing effect on the shape and amplitude of the perturbations. For a lead shell $\sigma_S < \sigma_F$; in this case the shear strength of the material does not have a stabilizing effect on the development of the perturbations. Although the perturbations have the same shape for lead and steel in the initial stage of motion, the prevailing effect of the inertial forces transform them into jets. We note that the results of numerical calculations [4], in spite of the different form of the determinant perturbations, do not qualitatively repeat the experimental data on the effect of the material strength of the shell on the behavior of the perturbations at the inner shell boundary when it collapses to the center of symmetry.

Thus, it has been established that when relatively thin monolayer cylindrical shells are accelerated explosively and when the determinant perturbations are on the inner boundary of the collapsing subshell, the behavior of the subshell is not described by simplified linear theory. In particular, the perturbation development does not have an oscillatory nature. The shear strength of the shell material has a substantial stabilizing effect on the development of the perturbations. These results can be used for developing a two-dimensional program for calculating this type of motion numerically.

LITERATURE CITED

1. G. Derentovich, "Strong compression of material with the aid of focused energy of explosives," Prikl. Mekh. Tekh. Fiz., No. 1 (1989).
2. V. A. Ogorodnikov and A. G. Ivanov, "Features of spallation of plates during the simultaneous initiation of an explosive charge at several points," Fiz. Goreniya Vzryva, No. 3 (1984).
3. L. V. Ovsyannikov, "General equations and examples," in: The Problem of Transient Motion of a Fluid with a Free Boundary [in Russian], Nauka, Novosibirsk (1967).
4. L. A. Elliot, "Calculation of the growth of interface instabilities by a Lagrangian mesh method," Proc. of 4th Symp. (Intern.) on Detonation, White Oak, USA, October 1965, Washington (1967).
5. V. K. Borisevich, V. P. Sabel'kin, S. N. Solodyankin, et al., "Dynamic characteristics of several metals and alloys," in: Pulsed Pressure Processing of Metals: A Collection of Articles, Khar'kov Aviation Institute, No. 9 (1981).
6. M. Malatynski and J. Klepaczko, "Experimental investigation of plastic properties of lead over a wide range of strain rates," Int. J. Mech. Sci., 22, No. 3 (1980).