REACTION OF CONVERGING CONICAL SHOCK WAVES IN POROUS SPECIMENS

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Given in this work are the results of studying the reaction of conical shock waves (SW) in porous specimens of aluminum, magnesium, potassium iodide, graphite, iron, and mixtures of aluminum with iron and aluminum with potassium iodide (50/50 and 70/30 by weight, respectively).

In order to create converging conical SW a specimen 1 was placed in a shell 2 of cast TG50/50 (density 1.68 g/cm^3, detonation velocity 7.65 km/sec) with an outer diameter of 40 mm and inner diameter of 20 mm (Fig. 1a). In the majority of tests the height of the shell was 60 mm. Initiation of shell detonation was carried out by a plane front generator 3 through an aluminum plate 4 of thickness 2 mm. By propagating through the shell, the detonation wave caused in the test specimens converging SW with the velocity D_0. At the upper end of the experimental assembly in the first series of tests a collection of plexiglass plates 5 with an air gap of 0.08 mm was placed. As expected, lighting-up of the gaps gives information about the configuration of the converging SW and their parameters in plexiglass. Recording of the process was carried out by a high-speed photorecorder with a free-running sweep rate of 3.75 mm/μsec, and the slit was set up over the assembly diameter.

Photograms for tests with aluminum specimens (Fig. 1b) of different initial density from 2.71 to 1.08 g/cm^3 are equalitatively similar and they show the existence of an irregular reaction which is characterized by formation of a Mach disk at the tip of a conical SW. In principle, the recording method used in the first series of tests may only give the actual shock wave picture in the case when there is absence of distortion for shock-wave geometry by additional waves, which may arise at the instant of reaction of a conical SW with the plexiglass barrier surface; in addition, there is no distortion from the SW in the plexiglass assembly caused by shell detonation products. In view of this, control tests were carried out (second series) in which the assembly of plexiglas plates was substituted by shaped plexiglas 5' (Fig. 2a). The height of the plexiglas cylinder added to the porous specimen was worked out on the basis of photograms already obtained from the first series so that there was simultaneous illumination from the detonation wave in the shell and the Mach disk in the specimen. The cylinder diameter was taken as a little greater than the diameter of the Mach disk d recorded in the first series of tests. The photogram obtained is presented in Fig. 2b. It can be seen that brightening of the gaps proceeds almost simultaneously, but illumination from the Mach disk according to size corresponds to that obtained previously in porous aluminum (ρ_{00} = 1.08 g/cm^3). Thus, if in photograms for tests with aluminum specimens (which were obtained in the first series) there is distortion, then it is insignificant.

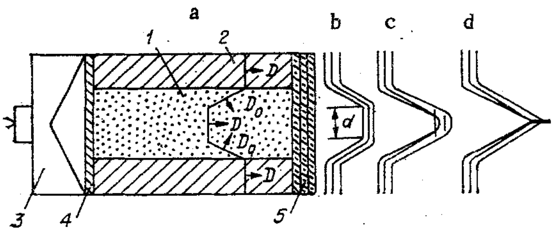

Fig. 1

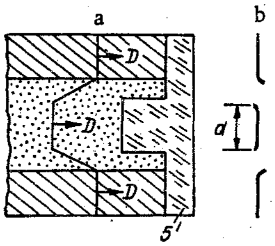

Fig. 2

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TABLE 1

Substance	ρ_{00}, g/cm^3	ε	d, mm	p_1, GPa	u	u^*	p^*	p_2
					km/sec		GPa	
Al	1,08	0,60	6,9	47±4	3,33	5,05	32,2	47,9
	1,22	0,55	7,6	45±3	3,20	4,72	36,0	46,2
	1,78	0,34	8,2	37±3	2,85	3,70	43,6	37,9
	2,25	0,17	8,5	26±2	2,44	2,82	45,0	30,0
	2,71	0	9,8	15±1	—	1,73	35,8	18,1
Mg	0,42	0,76	10,1	42±3	3,65	6,09	12,8	44,0
	0,80	0,53	10,5	39±3	3,44	4,97	23,1	40,0
	1,22	0,29	11,8	33±3	3,13	3,88	31,0	34,6
	1,55	0,10	12,1	29±2	2,76	2,99	33,8	28,8
	1,72	0	—	—	—	2,47	32,6	24,8
Graphite	0,80	0,64	6,4	50±4	3,37	5,14	24,2	44,5
	2,20	0	—	—	—	2,04	34,3	20,9
KI	1,32	0,57	—					
	3,10	0	~3					
Fe	2,50	0,68	—					
0,5Al + 0,5Fe	1,76	0,56	4,0	—	3,35	4,91	51,2	54,0
	2,55	0,37	—	43±4	3,06	3,99	65,4	47,0
	3,20	0,21	5,0	38±3	2,76	3,24	71,7	39,8
	4,03	0	—	—	—	2,17	66,9	27,9
0,7Al + 0,3KI	2,77	0,01	8,9	28±3	—	2,55	54,4	29,9

The process of forming a stationary Mach disk in the central part of channel is of quite complex nature and it is not considered in the present work. Basic experiments were carried out with a shell height of about 60 mm, but there were tests in which the shell height was 40 mm. In these cases photograms did not differ from those obtained for higher shells. This indicates that with the test arrangement given a stationary Mach disk is established at a distance of less than 40 mm and its propagation velocity is equal to the shell detonation velocity D.

The diameter of Mach disks d in tests with porous aluminum specimens decreases with an increase in specimen porosity. Similar photograms were also obtained in tests with porous magnesium specimens.

An irregular reaction with formation of a Mach disk is also observed in the first series of tests with porous graphite specimens (Fig. 1c), but reliable measurement of Mach disk diameter in this case is difficult due to the partial overlap of illumination of the first and second air gaps in the plexiglass assembly. Apparently this is caused by the fact that the propagation velocity of an oblique SW along the plexiglas—test substance boundary is less than the SW velocity in the plexiglas assembly caused by shell detonation products. Photograms obtained in the second series of tests are free of this drawback, and they made it possible to determine more accurately the Mach disk diameter and SW configuration. Quantitatively the shape of this record is similar to that presented in Fig. 2b.

For specimens of potassium iodide and porous iron in the first series of experiments it was not possible to record Mach reaction. There was overlap of the lighting-up of the first and second air gaps of the plexiglas assembly in the photograms obtained. In addition, in the central part of photograms for tests with porous iron specimens continuous illumination is recorded (Fig. 1d). Experiments carried out according to the second recording scheme showed the presence of a small Mach disk ($\sim$3 mm) in specimens of potassium iodide with a density of 3.1 g/cm^3. It is difficult to record the size of a disk less than 3 mm in a similar test arrangement, and therefore a study of specimens with greater porosity was not carried out. In tests with porous iron specimens it was possible to obtain simultaneous illumination of gaps at the end of the assembly and in the depth of the specimen with a plexiglas cylinder with a height of 25 mm and a diameter of 6 mm (shell height 55 mm). It is difficult to assess the existence of a Mach disk and its dimensions since the size of the illumination does not exceed 2 mm. With a reduction in the height of the cylinder introduced into the specimen, illumination in the central part increases to 3.5 mm with a

TABLE 2

Substance	ρ_0, g/cm^3	a, km/sec	b
Al	2,71	5,25	1,39
Mg	1,72	4,78	1,16
Graphite	2,2	4,057	1,763
KI	3,1	1,8	1,4
Fe	7,85	3,8	1,58
0,5Al + 0,5Fe	4,03	4,52	1,443
0,7Al + 0,3KI	2,79	3,82	1,5
Plexiglas	1,18	3,1	1,32

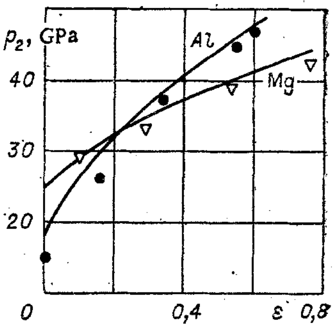

Fig. 3

height of 19 mm, but there is an increase in the time difference for emergence of waves. Apparently, in the case of specimens of porous iron the height of the shell used was insufficient in order to establish a stationary Mach disk in the central part of the channel.

There is definite interest in studying the reaction of SW in mixtures of different substances. Tests were carried out with specimens of mechanical mixtures of aluminum and potassium iodide with a density of 2.77 g/cm^3, which is close to the maximum of 2.79 g/cm^3, and aluminum with iron of different initial density. In the first mixture a Mach reaction was recorded. In a mixture of aluminum with iron the first method for recording photograms showed a Mach reaction with specimen densities of 3.2 and 2.55 g/cm^3, and with a density of 2.55 g/cm^3 partial overlapping of the illumination of the first and second air gaps was recorded. For a density of 1.76 g/cm^3, gap illumination overlapped and no clearly defined Mach disk was observed in the test arrangement. Photograms of tests obtained by the second recording scheme showed the existence of a Mach disk in specimens with a density of 3.2 and 1.76 g/cm^3.

Results of treating photograms are presented in Table 1 where initial specimen density ρ_{00}, relative porosity $\varepsilon = 1 - \rho_{00}/\rho_0$, Mach disk diameter d, and pressure p_1 in the plexiglas barrier in the region of the Mach disk are provided. It follows from experimental data that pressure p_1 increases, but the size of the Mach disk decreases with an increase in specimen porosity.

Conditions which are realized in a Mach disk are determined by the materials of a porous specimen, porosity, and propagation velocity D. Velocity D in the test arrangement selected is constant and equal to the shell detonation velocity (in all cases except tests with iron specimens). If consideration is given to shock compression of porous specimens within the limits of a unidimensional model [1] in which a porous specimen is substituted by a collection of parallel plates with gaps, then with normal assumptions relating to solid-substance compressibility the wave propagation velocity in the assembly is determined by the expression

$$D^{-1} = (1 - \varepsilon) D_1^{-1} + \varepsilon (2u)^{-1},$$

where D_1 is wave velocity; u is mass velocity at the SW front in the plate. The final condition with shock compression for a porous specimen (p^*, u^*) within the limits of this model lies in isoentropy for a solid substance, provided from a condition with mass velocity u. Calculated valeus of p^*, u^*, and u are presented in Table 1. Also given for comparison are calculated SW parameters for solid specimens and corresponding pressures in the plexiglas barrier. In the calculation use was made of shock adiabatic curves for solid materials in the form $D = a + bu$. Initial densities ρ_0 and values of coefficients a and b were taken from [2], and they are presented in Table 2. Shock adiabatic curves for solid mixtures were plotted on the assumption of the additive nature of specific volumes for components under equal pressures [3].

From the known condition in the region of the Mach disk, pressures p_2 were calculated in the plexiglas barrier which are in good agreement with experimental values of p_1 (Table 1 and Fig. 3). The small systematic increase in the calculated values over experimental values for metal specimens may be explained by SW attenuation for the measurement base. For graphite specimens, a reduction in p_2 is observed which is probably connected with nonfulfilment of assumptions about the reflecting nature of isoentropy and the shock adiabatic curve for graphite on p–u coordinates, which is used in calculations for a layered model.

The study carried out showed that with reaction of converging conical SW in porous specimens of aluminum, magnesium, graphite, and mixtures of aluminum with iron and aluminum with potassium iodide, a Mach reaction is observed. In the test arrangement used with porous iron specimens no stationary Mach disk was established, and apparently this is connected with the insufficient height of the shell.

In the case of Mach reaction there is an increase in pressure transmitted to the plexiglas barrier with an increase in specimen porosity and a reduction in Mach disk size.

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PROPAGATION OF A SPHERICAL WAVE IN NONLINEARLY COMPRESSIBLE AND ELASTOPLASTIC MATERIALS

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The problem of spherical wave propagation in soil under the action of an intense uniformly decreasing load $\sigma_0(t)$ applied to the boundary of a cavity with radius r_0 is considered. Soil with a high stress level is modeled either by ideally nonlinearly compressible or elastoplastic material, taking account of linear irreversible unloading for the material. In contrast to [1-7], in order to describe material movement use is made of strain theory [8] with determining functions $\sigma = \sigma(\varepsilon)$, $\sigma_i = \sigma_i(\varepsilon_i)$, where ε, ε_i, σ, σ_i are the first and second invariants of strain and stress tensors. During material loading these functions are presented in the form of polynomials

$$\sigma(\varepsilon) = (\alpha_1 + \alpha_2|\varepsilon|)\varepsilon,\ \sigma_i(\varepsilon_i) = (\beta_1 - \beta_2\varepsilon_i)\varepsilon_i,$$

in which constant coefficients α_i, $\beta_i (i = 1, 2)$ are determined by experiment, taking account of the triaxial stressed state of soil. Solution of the problem is constructed by an analytically reversible method, with prescribed shape for the shock-wave (SW) surface in the form of a second-degree polynomial relating to time t and a numerical method of characteristics for a prescribed arbitrarily decreasing load $\sigma_0(t)$. On the basis of the analytical equations obtained, calculations are carried out for material parameters (including loading profile) in a computer and stresses and mass velocity of plastic and elastoplastic materials are compared.

This work is a continuation of [9, 10] for studying the characteristic features of spherical wave propagation in soils and the behavior of its parameters with intense effects.

1. Let at the boundary of a spherical cavity $r = r_0$ a uniformly decreasing load $\sigma_0(t)$ be applied. In the case of considering the problem within the limits of a nonlinearly compressible material with fulfillment of the first expression (0.1) taking account of $\sigma(\varepsilon) = \sigma_{rr} = \sigma_{\varphi\varphi} = \sigma_{\theta\theta} = -p$, $\varepsilon = (1 - \rho_0/\rho) > 0$ (p is pressure, ρ_0 is initial material density), a spherical SW $r = R(t)$ will propagate in the soil, at whose front the soil is instantaneously loaded in a nonlinear fashion while beyond it in the region of disturbance there is

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