3. H. L. Brode, "Blast wave from a spherical charge," Phys. Fluids, 2, No. 2 (1959).
4. A. S. Fonarev and S. Yu. Chernyavskii, "Calculation of shock waves with the explosion of spherical charges of explosive substances in air," in: Proceedings of the Second International Colloquium on the Gas Dynamics of Explosion and Reacting Systems [in Russian], Vol. 3, Izd. Vychislitel'nyi Tsentr Akad. Nauk SSSR, Moscow (1971).
5. S. M. Kogarko, V. V. Adushkin, and A. G. Lyamin, "Investigation of the spherical detonation of gas mixtures," Nauchno-Tekh. Probl. Goreniya Vzryva, No. 2 (1965).
6. M. J. Balcerzak and M. R. Johnson, "Use of detonable gas explosions for blast and shock studies," The Shock and Vibration Bulletin, Bulletin 37, Part 4, January (1968).
7. R. D. Richtmyer and K. W. Morton, Difference Methods for Initial-Value Problems, Wiley (1967).
8. K. P. Stanyukovich, "Not Fully Established Motions of a Continuous Medium [in Russian], Izd. Nauka, Moscow (1971).

INVESTIGATION OF THE SPECIAL CHARACTERISTICS OF THE PROPAGATION AND REFLECTION OF PRESSURE WAVES IN A POROUS MEDIUM

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In view of the wide use of porous materials in technology there arises the need to investigate the dynamic processes taking place in them. The main difference between a porous substance and a solid condensed material is the fact that the condensed phase occupies only part of the volume of the porous medium, which leads to a lowered volumetric density and to a large degree of compressibility. There is particular interest in polymeric media with a small density on the order of 20 kg/m^3, in which up to 98% of the volume is occupied by the gas phase. Such a density is achieved if the medium has a cellular structure of the foam, for example, in polyurethane foam plastics. At the present time, only the elastic properties of polyurethane foam plastics under the action of cyclic [1] and impact [2, 3] loads are known. Questions of the formation of pressure waves in such a medium, with the refraction in it of a shock wave from the gas, of the structure of the wave propagating over the foam plastic, as well as the special characteristics of its reflection from the interface, remain unclear. In the experiments described below, an investigation was made of pressure waves with intensities up to 20 bars in elastic polyurethane foams (PUF) with a porosity of 0.98 and the special characteristics of the reflection of such waves from a rigid wall were also determined.

1. Experimental Unit

The experiments on the study of the structure of pressure waves in a porous medium were made in a shock tube of rectangular cross section 45 • 30 mm, shown in Fig. 1. The high- and low-pressure chambers, denoted by the numbers 1 and 2, have a length of 0.4 and 1.5 m, respectively. The unit is provided with piezoelectric pressure pickups 3-6, with natural frequencies of about 30 kHz. Pickup 3 triggers the scanning of the oscillograph, pickups 4, 5 record the pressure in the passing wave, and pickup 6, that in the reflected wave. The readings of the pickups were recorded in a five-beam Cl-33 oscillograph; the signals of pickups 4 and 5 are fed to channels 1 and 2 (counting the beams from the bottom up), and, of 6, simultaneously to channels 3-5, with different sensitivities.

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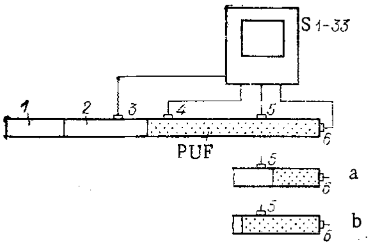

Fig. 1

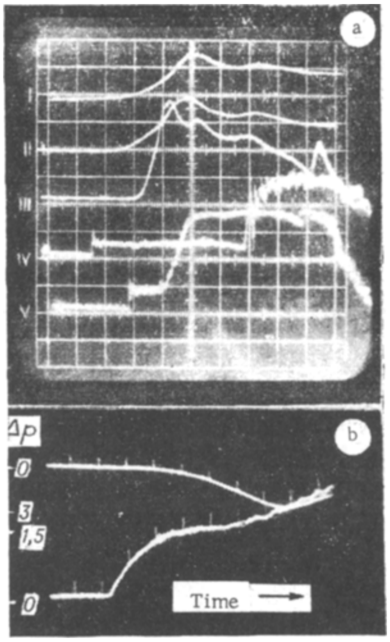

Fig. 2

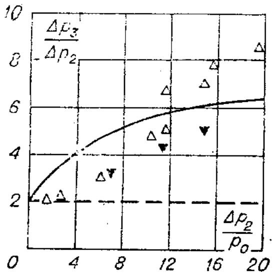

Fig. 3

In the experiments, a study was made of the motion of waves in blocks of polyurethane foam with a length from 0.15 to 0.6 m, mounted in the low-pressure chamber of the shock tube. A pressure wave in the polyurethane foam was generated with the reflection of an air shock wave at the foam plastic—air interface. The pressure in the wave is given by the pressure of the incident shock wave Δp_1. An investigation was made of the motion of waves with an intensity of $\Delta p_2 = 1.5$-20 bar, with an initial pressure of the gas $p_0 = 1$ bar. The principal measured parameters of the waves were the rate of propagation, the pressure in the waves passing through, the pressure of waves reflected from a rigid wall, and the degree of damping of the waves in polyurethane foam. The speed of sound was determined in the same materials. For this purpose, the low-pressure chamber was completely filled with the material being investigated and was then discharged into the evacuated high-pressure chamber. The speed of sound was determined from the motion of the head of the rarefaction wave in the polyurethane foam block and was measured by a resonance method for vibrations with a frequency up to 1 kHz. With measurements of the speed of sound, as well as of the rate of propagation of waves with amplitudes from 1.5 to 3 bars, and their reflection from a rigid wall, an OK-24 two-beam oscillograph was used. The resonance frequencies were determined using a ChZ-33 frequency meter.

2. Results of Experiments

Figure 2a shows an oscillogram of the readings of pressure pickups with the reflection of an air shock wave with $M = 2.0$ and an amplitude of 19.6 bars from the surface of a block of polyurethane foam with a length of 0.15 m. The time scale in channels 1, 2 was 300 μsec/division, and the scales of the pressure were 7.5 and 11 bar/division, respectively. Due to the considerable difference in the acoustic resistances of the air $\rho_1 c_1 = 4.2 \cdot 10^2$, and of the porous medium $\rho_2 c_2 = 4 \cdot 10^3$ kg/(m$^2 \cdot$sec), with reflection a shock wave arises, which is seen on the oscillogram as the second step of the pressure. The wave, refracted in the polyurethane foam, is then reflected from the closed end of the tube, which is recorded by pickup 6 in channels 3-5. With a pressure scale of 34.6 bars/division, the time scales in channels 1-3 coincide. In channels 4, 5, the same signal is represented with a scanning time of 100 μsec/division and a sensitivity of 60 and 80 bars/division, respectively.

The experiments showed that the pressure in a wave in porous media, in distinction from gaseous media, rises gradually in a time on the order of a few hundred microseconds. The time of the rise is found to be greater the weaker the pressure wave. Figure 2b shows an oscillogram of the reflection of a wave with an amplitude of 1.5 bars from a solid rigid wall. On the lower beam, there is recorded the incident wave with the initial phase of the reflection, measured by a pickup installed at a distance of 0.1 m from the wall. On the upper beam there is recorded the pressure recorded by the end pickup. The time markers follow every 300 μsec.

TABLE 1

Δp_1	Δp_2	Δp_2(water)	Δp_2 (PUF)
0,6	1,48	2,96	3,0
1,0	2,75	5,0	6,0
1,9	6,23	12,4	19
2,8	10,4	20,8	50
4,5	19,6	39,2	120

Measurement of the velocity of the wave in blocks of material with a length of 0.6 m discloses damping of the wave, the degree of which depends on the amplitude. Specifically, in a length of 340 mm, the velocity of the wave falls from 320 to 200 m/sec with a pressure drop at the front of 4 bars, and from 380 to 280 m/sec with a pressure drop of 12 bars. Such a drop in the velocity far exceeds the error in its measurement, amounting to 4-5%.

Along with the velocity, there is also a decrease in the pressure behind the front with its motion over the material. The degree of damping is lowered with a decrease in their intensity. Specifically, a wave with $\Delta p_2/p_0 = 14$ is damped at a rate of 6, with $\Delta p_2/p_0 = 7$, of 3 bars/m. The damping of waves weaker than $\Delta p_2/p_0 = 5$, lies within the limits of the error of the measurement and does not exceed 10% in a length of 0.34 m.

The results of measurement of the parameters of reflected waves are of the greatest interest. Figure 3 shows a curve of the dependence of the ratio of the pressure in the reflected wave Δp_3 to the pressure in the incident wave on the value of $\Delta p_2/p_0$. The dependence established in the experiments is represented by the open triangles; the solid line shows the degree of increase in the pressure at the wall with the normal reflection of a shock wave in air, calculated using the well known Izmailov formula [4]. The same dependence for a low-compressibility medium of the type of water is shown by the dashed line.

Analyzing the experimental data, the conclusion can be drawn that the compressibility of the elastic polyurethane foam under consideration is small only in the region of pressure drops up to 2-3 bars: such waves for this material will be weak. Their velocity differs only slightly from the rate of propagation of sonic vibrations, i.e., from a value of $(2.0 \pm 0.1) \cdot 10^2$ m/sec, while the degree of increase in the pressure with reflection (the coefficient of reflection) ~ 2. With a rise in the intensity of the incident wave, the coefficient of reflection rises and, starting from a pressure of ~ 12 bars, exceeds its value in the gas.

The pressure of the reflection for elastic polyurethane foam is appreciably lowered in the case where it has a skeletal structure, i.e., the barrier films in the cells of the material are removed. The results of the measurements are shown by the dark triangles in Fig. 3.

The absolute values of the pressures, expressed in bars, attainable with the normal reflection of a shock wave from a rigid wall, are given in Table 1 for air, water, and polyurethane foam, differing in density and compressibility: Δp_1 relates to a shock wave, propagating over the gaseous medium, and then being refracted in the denser medium; Δp_2 arises with the decomposition of the discontinuity and is actually equal to the pressure of a wave in a gas reflected from a rigid wall; Δp_2 in the third column shows that, in water, reflection from the wall takes place in accordance with an acoustical law. The last column gives the results of measurements of the pressure with the reflection of a wave with the pressure Δp_2 in polyurethane foam.

It can be seen from Table 1 that the replacement of a continuous medium by a porous medium leads to a considerable increase in the reflection pressure.

The possibility of attaining high pressures with the reflection of a shock wave, propagating over a porous plastic, from a rigid wall is obviously explained by the fact that the solid phase of the porous medium is set into motion behind the wave. This effect is minimal for weak waves; therefore, it leads to an acoustical result with reflection from a rigid wall. For strong waves, the motion of the solid phase, in which is concentrated the main mass of the porous medium, promotes an increase in the pressure in the reflected wave, in comparison with the case of a pure gas. The factors which bring about a lowering of the rate of mass transfer also bring about a lowering of the pressure behind the reflected wave. Precisely for this reason, there is a lowering of the reflection pressure with the liquidation of the film-partitions in the cells of the material. The skeletal structure of the material, considerably decreasing the resistance to the gas flow, leads to a lowering of the transfer rate in the direction of the motion of the wave and, in the final analysis, to a lowering of the reflection pressure.

LITERATURE CITED

1. K. I. Mal'tsev, "Elastic properties of a semirigid polyurethane foam plastic with small deformations," Akust. Zh., 13, No. 3 (1967).
2. V. M. Kryachko and G. A. Ostroumov, "Compression waves in a porous plastic," Akust. Zh., 13, No. 3 (1967).
3. R. Linde, L. Seaman, and D. Schmidt, "Shock response of porous copper, iron, tungsten, and polyurethane," J. Appl. Phys., 43, No. 8 (1972).
4. Yu. S. Yakovlev, The Hydrodynamics of Explosion [in Russian], Izd. Sudpromgiz, Leningrad (1961).

CALCULATION OF AN EJECTION EXPLOSION IN A RADIAL APPROXIMATION

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Equations are derived describing the motion of a medium with an ejection explosion, under the assumption that the medium is incompressible and moves in a radial direction away from the center of the explosion. Here account is taken of the tangential stresses between the moving layers of the medium. A comparison of the calculations of the velocities of the motion of the dome and the dimensions of the craters formed showed good agreement, both with model experiments on the ejection of sand, and with large-scale ejection explosions.

1. Introduction

The development of an ejection explosion in soil or rock with time can be represented in the form of three basic stages [1, 2]. The underground-explosion stage lasts from the moments of the detonation of the charge up to the arrival of the wave at the surface. Here the motion of the medium is close to spherical symmetry. In the second stage, starting after reflection of the wave from the free surface, a dome develops. This stage continues up to the moment of the breakthrough of the gases from the cavity to the atmosphere. After this, the dome breaks down rapidly and, during the succeeding moments of time, in the third stage, there is a ballistic dispersion of particles between which there is very little connection.

The two-dimensional, not fully established motion of the medium in the second stage determines to a considerable degree the dimensions of the future crater. A complete investigation of this motion is complicated and is possible only using high-speed computers. In [3-6], methods are proposed for calculating the equations of an elastoplastic medium with two spatial variables. Such calculations require a large amount of machine time; therefore, they are not very suitable in cases where a large number of variants is needed for the analysis.

To make preliminary calculations aimed at clarifying the effect of the parameters characterizing the properties of the medium and the conditions of the conduct of the explosion on the ejection crater, it is expedient to use less complicated methods, requiring a small amount of machine time for each variant. In the construction of a simple ejection model, in the present work the following assumptions are used: 1) the motion of the medium in the second stage takes place only in a radial direction; 2) the medium is incompressible.

The first postulation is based on the fact that the development of the dome starts after the end of the spherically symmetrical underground-explosion stage, in which the velocity has a radial direction.

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