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CONTINUOUS RECORDING OF THE SPEED OF A SHOCK WAVE IN POROUS METALS AND ITS APPLICATION TO THE MEASUREMENT OF THE SPEED OF SOUND IN VARIOUS MATERIALS

Yu. L. Alekseev and V. P. Ratnikov

UDC 539.63

In studying various materials the mechanical parameters of a shock wave are presently determined by recording the transit time of the wave between fixed points and determining the average speed of the shock wave between these points. In investigating the shock compressibility of porous metals a great deal more information can be obtained by a continuous recording of the position of the shock wave.

The porous sample under study, pressed from metal powder, consists of metal grains, and in the uncompressed state has a finite nonzero resistance made up of the contact resistances between grains. When a shock wave propagates through such a material the thickness of its uncompressed part is decreased and its resistance is changed. By passing a steady current in a direction perpendicular to the wave front and recording the potential drop across the sample with an oscillograph, a continuous trace in (x, t) coordinates can be obtained representing the shock-front trajectory through the sample.

Figure 1 shows a schematic diagram of the experimental arrangement. The porous sample 1 is placed on the metal screen 2 which also serves as an electrode. The shock wave is produced by the impact of the flyer plate 3. On the end surface of the porous sample there is a second electrode 4 whose edges must not protrude into the region subjected to the action of lateral relaxation.

The electric field in the sample will generally not be uniform. The current lines, shown by the open curves in Fig. 1, were determined by using an electrolytic model. The resistance of the sample is determined mainly by the resistance of its central part under electrode 4. In order not to have to correct in the experiment for that part of the field where the current lines are distorted, the sample was made in two parts: the main part, placed on the screen, in which the measurement is performed, and an auxiliary part. To separate the trace of the motion of the shock wave through the main part of the sample from that through the auxiliary part, a layer of another porous metal 5 having a smaller resistivity was deposited on their boundary, for example, nickel powder on copper, or electrical contacts 6 of 0.2-mm-diameter enameled moisture-resistant wire were placed as shown, as is usual in the electrical contact method [1]. The contacts are connected to the electrodes. In the first

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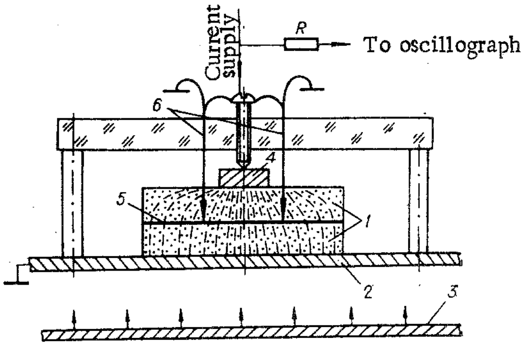

Fig. 1

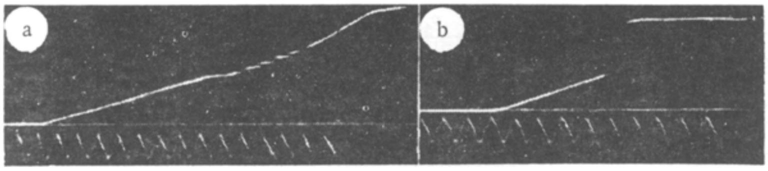

Fig. 2

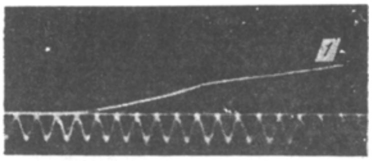

Fig. 3

case, as the shock wave passes the boundary between the component parts of the sample, the smoothness of the trace is changed by the appearance of a horizontal part; in the second case, with the breakdown contacts there is also a disruption of the smooth trace. Typical oscillograms are shown in Fig. 2.

When the samples are uniform in density and the speed of the shock wave is constant, the shock-front trajectory through the sample is rectilinear in the (x, t) coordinate system. If the striker is thin enough, the rarefaction wave propagating with the speed of sound from the rear of the striker overtakes the shock front at a point in the porous sample. At this point the rectilinear nature of the trace of the shock-front trajectory is disrupted. Figure 3 shows an oscillogram of an experiment in which the rarefaction wave overtakes the shock front at point B, after which the speed of the shock wave begins to decrease. By using the overtaking-relaxation method [2] it is not difficult to calculate the speed of sound in the porous metal from the coordinates of the point obtained.

The coordinates of the points where the rarefaction wave overtakes the shock front in a porous metal can be used to calculate the speed of sound in the screen material under shock compression.

Let us consider the (x, t) diagram in Fig. 4. A shock wave D_2 is produced in the screen under study by the impact of the plate. The first characteristic $c_2 + u_2$ of the rarefaction wave traveling from the rear surface of the striker would overtake the shock wave D_2 at point A if the screen were thick enough. Knowing the coordinates at point A, the speed of sound c_2 in the screen material can be calculated. Ordinarily, the coordinates of this point are determined by measuring the speed of the free surface W as a function of the thickness of the material under investigation, using the electrical contact method in a long series of experiments [2].

We show how to solve this problem by using a porous metal. We limit the thickness of the screen to a certain value $h < x_A$ and place the sample of porous metal on its surface as described above. As the shock wave D_2 passes the interface between the screen and the porous metal, the discontinuity is destroyed and shock wave D_1 travels through the porous metal. Now the rarefaction wave overtakes the shock front at point B in the porous metal. Figure 4 shows two positions of points B (B_1 and B_2) corresponding to screen thicknesses h_1 and h_2.

Points B_i are located at the vertices of the figures KLMB formed by the wave rays. In experimental arrangements such that the change of amplitude of the shock wave can be neglected until the arrival of the rarefaction from the rear of the striker, as can be achieved by a proper choice of thickness of the striker and screen, these figures are geometrically similar. Since the sides of these figures are parallel, and part of the vertices are located on

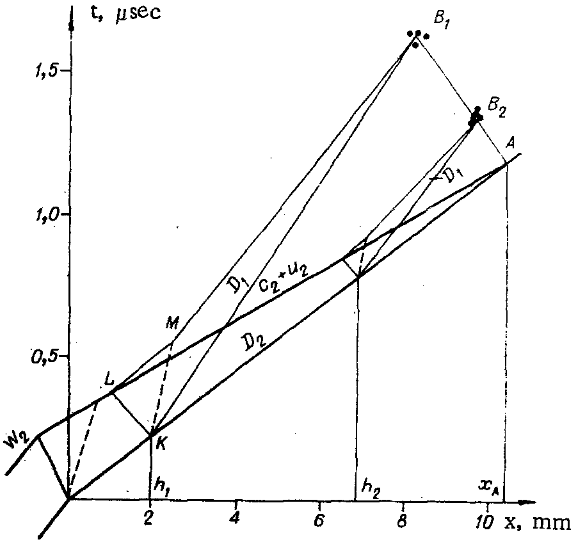

Fig. 4

TABLE 1

Thickness of screen	Thickness of striker, mm	Sample of porous copper		Point where front is overtaken		Speed of sound in screen material, km/sec	
		thickness, mm	density, g/cm³	x, mm	t, μsec	measured	from results of [12]
1,98	1,98	9,92	2,95	8,29	1,610	9,15±0,02	9,15
2,00	1,96	9,83	2,98	8,64	1,593		
1,99	1,99	9,94	2,94	8,33	1,561		
2,00	1,96	9,94	2,94	8,42	1,604		
6,97	2,01	4,89	2,97	9;70	1,307		
6,92	2,00	4,88	3,00	9,83	1,317		
6,98	1,98	4,92	2,97	9,81	1,327		
6,98	1,97	4,87	3,00	9,84	1,345		
6,96	1,96	4,88	2,99	9,91	1,317		

straight lines intersecting at point A, the vertices B_i are located on the straight line BA; i.e., the limiting position of points B as the thickness of the screen is increased to x_A is point A. The coordinates of point A can be found from the coordinates of the two points B_1 and B_2.

We shall show a practical application of the method presented for determining the speed of sound by determining the speed of sound at high pressure in aluminum, a material which has previously been well studied in this respect. A 2-mm-thick aluminum striker moving 5.60 km/sec hits an aluminum screen. We measure the shock-front trajectory in samples of porous copper on screens of thickness h_1 = 2 mm and h_2 = 7 mm. The state in the screen (p = 692 kbar, D_2 = 9.03 km/sec, u_2 = 2.80 km/sec) is determined by the reflection method using the results of [3].

The experimental results are shown in Table 1 and Fig. 4. The value obtained for the speed of sound agrees with the result in [2] for the same conditions.

This example of the application of the proposed method indicates the possibility of replacing the method of measuring the speed of sound by the relation (W — x). The measurement in this case is as accurate as in the previous method, and the volume of experimental work is reduced.

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STEADY-STATE STRAINING OF SOLIDS

Yu. I. Fadeenko

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The concept of the dynamic yield point σ_d is used in investigations concerned with the mechanics of plastically deformable solids. It is understood that, for sufficiently large values of the plastic strain γ, the straining process is stabilized in a certain manner, and the stress causing further straining becomes a certain function of the deformation rate $\dot{\gamma}$ and the temperature T, $\sigma = \sigma_d(\dot{\gamma}, T)$, which is characteristic for the material in question and determines the dynamic yield point. The problem of the existence of $\sigma_d(\dot{\gamma}, T)$ is solved within the framework of the mechanics of continuous media on the basis of experimental data. If the experimental data agree with the existence of $\sigma_d(\dot{\gamma}, T)$, the problem consists in choosing the continuous medium model that has a suitable determining equation. However, if the concept of discrete elemental structure of matter is used, it becomes necessary to interpret the existence of the function $\sigma_d(\dot{\gamma}, T)$ on the basis of the dislocation theory. The experimental data presently available are apparently still insufficient for a definitive solution of this problem. Let us discuss the existing possibilities, using, for the sake of convenience (as an illustrating example), the simple case of pure shear, produced by an "effective system of dislocation glide" with suitably averaged characteristics.

Assume that the maximum shearing stress σ acts in the direction of glide, G is the shear modulus, N is the dislocation density, v is the rate of dislocation glide, ε is the elastic (potential) part of the total energy of formation of a unit-length dislocation filament, and b is the absolute value of the Burgers vector. We shall represent the rate of change in shearing strain as the sum of the elastic and the plastic components:

$$\dot{\gamma} = \dot{\gamma}_e + \dot{\gamma}_p = \dot{\sigma}/G + bNv.$$

In particular, $\dot{\sigma} = 0$ and $\dot{\gamma} = bNv$ under steady-state conditions; then the necessity for the existence of a single-valued dependence $Nv = f(\sigma, T)$ follows from the assumption about the existence of a dynamic yield point. Such a dependence could exist in the following cases:

1. The value of N is arbitrary, but the law of collective motion of dislocations differs from the law of motion of a single dislocation and also has a special form:

$$v(\sigma, T, N) = f(\sigma, T)/N,$$

while the establishment of flow constitutes the establishment of a regular structure in the aggregate of dislocations. We shall confine ourselves to the statement of this variant without touching upon the possibility of its realization and pass to the following, more probable, variants.

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