In the number representing the i-th row of the coupling matrix, the ones are at the k-th, i-th, and l-th places. To represent the i-th and j-th columns of the coupling matrix, represented in the form of a column of binary numbers, it is necessary to subtract $2^{l-1}$ from the k-th, i-th, and l-th numbers, and to add $2^{j-1}$, and to subtract $2^{l-1}$ from the n-th, j-th, and m-th numbers and to add $2^{j-1}$. We assume that the twos in the corresponding degrees are represented in binary form. After the transposition of the columns, we change the places of the i-th and j-th number, and also the i-th and j-th elements of the body of transpositions. Then we go over to the next stage of renumbering.

To illustrate the operation of the algorithm, we will examine the renumbering of the nodes of the grid of finite elements for the region shown in Fig. 1a. The coupling matrix corresponding to the initial numbering of the nodes of the grid is shown in Fig. 1b. As a result of the transpositions of rows and columns according to the suggested algorithm, the coupling matrix assumed a band-shaped aspect (Fig. 2a). The numbering of the nodes of the grid of finite elements corresponding to the obtained coupling matrix is shown in Fig. 2b. To the left of the coupling matrix, the body of transpositions is printed, and to the right the decimal numbers equal in value to the binary numbers representing the rows of the coupling matrix.

It can be seen from Fig. 2b that the suggested algorithm leads to frontal numbering of the nodes of the grid of finite elements. This is due to the fact that in the coupling matrix represented by a column of binary numbers, the coupled nodes correspond to numbers containing two to the same power.

Thus, the suggested algorithm is one of the modifications of the frontal methods. Like in other frontal methods, the bandwidth of the coupling matrix depends on the node selected as the first one, and it need not correspond to the smallest possible width. The selection of the first node leading to the minimal bandwidth may be carried out, e.g., with the aid of the procedure suggested by Collins [4].

LITERATURE CITED


HIGH-SPEED IMPACT COMPRESSION
TESTING OF METALS

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Materials testing with high-speed deformation is of interest in connection with the development of models for material mechanical behavior under shock loading as a basis for designing structural elements to operate under impact and explosion, and the choice of metal treatment schedules using impact energy sources.

The split Hopkinson bar method is used extensively to test materials in compression with a uniaxial stress state [1, 2]. A specimen in the form of a thin disk is strained between the flat ends of transmission and sensing bars with passage of a loading wave caused by a striker on the free end of the transmission bar. The small specimen thickness provides rapid stress equalization and with an insignificant frictional effect at the ends the stress state in the specimen is close to a uniform and uniaxial situation.

Strain rate is determined as the difference in displacement rates of the bar ends adjacent to the specimen calculated by the unidimensional theory of elastic longitudinal wave propagation. The amount of strain is calculated as the mean longitudinal force on the contact surfaces between the bars and the specimen according to the recorded longitudinal strain of the bar at a certain distance from these surfaces.

Fig. 1. Layout for performing the experiment: 1) specimen; 2) striker; 3) packing plate; 4) dielectric sensor; 5) Plexiglas (b = 2 mm, h = 3 mm, s = 2 mm).

Fig. 2. Calibration relationship (a) and typical pressure oscillograms (b) for tests on alloy D16M specimens.

The maximum loading amplitude on the specimen is limited by a permissible wave amplitude that does not cause noticeable inelastic strain in the bars, and the maximum strain rate is limited by the curvature of the wave front, reducing with its propagation through the bar from the loaded end due to dispersion effects. This method has been used to study low yield point materials (mainly aluminum and its alloys [3, 4]) in the strain rate range up to $10^4$ sec$^{-1}$.

With impact loading by the striker directly on the specimen surface (without the transmission bar) the strain may be increased by an order of magnitude [5], however, the accuracy for strain rate and force decreases sharply. This is caused by the necessity of evaluating strain in the striker, and experimental determination of this is difficult.

In addition, accurate determination of the displacement rate for the contact surface of the sensing bar with the specimen according to longitudinal strain of the bar surface with wave propagation is distorted due to wave dispersion (at high loads and high loading rate the stress across the bar section is not uniform and it differs markedly from a uniaxial stress), and superimposition of radial vibration caused by a transverse inertial dynamometer makes processing of the oscillograms difficult and excludes the possibility of obtaining reliable data during prolonged tests close to the period of these vibrations.

A method has been developed at the Institute of Strength Problems, Academy of Sciences of the Ukrainian SSR, for testing materials in compressive impact at high rates, making it possible to avoid the distorting effect of radial inertia.

The test layout is presented in Fig. 1. Specimen 1 in the form of a disk having slots with spacing h is strained between the flat surfaces of striker 2 and packing plate 3 in a pneumatic ram [6]. In this way the thin strip of material is strained under plane strain conditions (there is no strain in the direction of the strip axis), and its resistance to plastic shear according to the Mises criterion may be compared with shear resistance under uniaxial stress conditions. Strip width b is chosen so that the force used to strain it does not cause marked plastic strain in the striker of packing plate. The material of the latter is in a constrained plastic strain condition and this helps to reduce strains arising in it. Specimen strain is associated with wave propagation through the striker and packing plate. At a distance from the contact surface with the specimen equal approximately to the grid spacing the wave in the plate is close to a plane condition, and recording its intensity in this region unaffected by a lateral loading wave characterizes specimen strain resistance. Specimens made of aluminum alloy D16M sheet were tested by this method.

A dielectric pressure sensor [7] located between the back face of the packing plate and the Plexiglas (see Fig. 1) was used in the experiments to record wave intensity in the dynamometer plate.