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FUNDAMENTALS OF STRENGTH AND DURABILITY CALCULATIONS FOR HIGH-PRESSURE APPARATUS ELEMENTS

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The high-pressure apparatus for the synthesis of materials are devices of repeated application. They comprise many elements made of materials with different elasticity, plasticity and thermal conductivity characteristics.

The dependence of the mechanical characteristics of these materials on the stressed state mode and temperature causes problems in analyzing their stressed–strained state.

Theoretical aspects of the mechanics of deformable bodies have been considered and an example of numerical calculation has been presented for the fields of temperature and mechanical stresses in load-bearing elements for different models of high pressure apparatus. In this case the pressure and temperature dependence of metals and non-metals properties, substantial thermoplastic deformations and contact interaction of separate elements in high-pressure apparatus have been taken into account. The thermoplastic critical state of the reaction cell container made of natural stone has been investigated. The selection of critical mechanical characteristics (strength and durability) taking into account the scale effect has been theoretically proved.

The distribution of equivalent stresses and the durability of the elements of different modes of the high-pressure apparatus has been considered. The effect of the scale factor has been investigated. Estimated values have been compared with experimental ones obtained for the models of elements of the high-pressure apparatus.

The problem has been considered concerning the numerical determination of temperature and stress fields in an axisymmetric high-pressure apparatus (HPA) of the recessed anvil type used to synthesize superhard materials. The possibility has been examined of estimating the strength and durability of HPA elements under repeated heating and loading.

The temperature distribution is determined by the finite element method (FEM) applied to the solution of a coupled nonlinear and nonstationary problem of the electrical and thermal conductivities of HPA elements under heating the reaction cell by the direct passage of the low voltage current [1]. The high-pressure apparatus of conventional type, one quarter of the axial section of which is shown in fig. 1, comprises inhomogeneous elements.

The reaction cell container is made from different rock materials, e.g. lithographic stone. The model of ideally plastic isotropic material [2] is used to determine its limiting state due to high plastic compression strain. Using the hypothesis of complete plasticity [3] we consider the problem to be statically determinable and apply the slip line method for its solution. We use the methods for a determination of constants in the equations of the limiting surface of ideal plasticity described by Coulomb's law [4]. Making use of the temperature field obtained and the temperature dependence of the constants included in the condition of Coulomb's plasticity limiting state the problem for a container of predetermined shape and size has been numerically solved by means of a "plasticity" program package for computer-aided calculations [3, 4]. The calculations resulted in obtaining the distribution of contact normal σ_c and tangential τ_c stresses at the container–matrix interface (fig. 2). These data are the initial ones for calculating the matrix strength. The value of stress jump at the media interface is influenced by a number of factors. Thus, allowing for the temperature dependence of the container material properties results in a considerable reduction of the calculated value for stress jump approximating the calculated model of straining to the real one which is physically valid.

The obtained characteristics of the container

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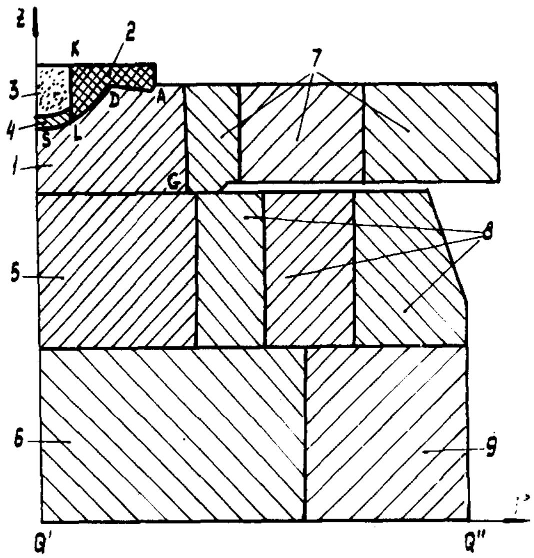

Fig. 1. Axial section of the high-pressure apparatus of recessed anvil type: 1, hard alloy matrix; 2, reaction cell container; 3, reaction mixture; 4, heater; 5, supporting plate insert; 6, backing plate insert; 7,8,9, steel rings fitted-on.

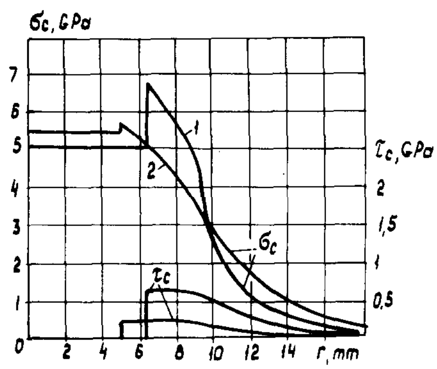

Fig. 2. Distribution of contact normal σ_c and tangential τ_c stresses on the matrix operating surface which is obtained (1) without and (2) with the temperature dependence of container material properties.

limiting state make it possible to define the following criterion of the container failure: σ_r stresses in the reaction mixture should be less than the calculated value of radial stresses at the K-point of the container ($\sigma_r^m \leq \sigma_r^c$). Besides, it is evident that the σ_r^c value is influenced by geometric parameters not for the whole surface of the lune, but only for a region adjacent to the recess edge. The friction value in this region [3] is also of great importance for the results of calculation.

Special programs have been composed for the computer-aided calculation of the stressed state of metal elements in the HPA of widely known types ("lentil", belt, toroid, etc.). Contact problem of stress determination when joining steel binding rings by fitting them one upon another and upon a hard alloy matrix has been solved by the finite element method reported in ref. [5]. In the calculated example the region investigated was divided into 1444 trianglar elements joined in 809 nodes with a linear approximation of displacements, the matrix was divided into 500 elements. The final stress–strained state of HPA elements under loading was determined by the summation of operating and residual stresses caused by fitting separate elements into a single block. Vertical displacement of the lower end of the backing plate was considered to be absent.

Consider the results of the matrix limiting state calculation. Laboratory tests on samples of BK-6 tungsten–cobalt alloy with different types of the stressed state have shown that the limiting surface for the strength of this alloy is described in the most complete manner by the surface corresponding in its shape to the Pisarenko–Lebedev criterion [6]. The calculations were carried out taking into account the type and nonuniformity of the matrix stressed state as well as BK-6 alloy sensitivity to scale effect [7]. The following values of the material mechanical constants included in the criterion have been found experimentally: the ultimate tensile, compression and torsion strengths are found to be 1.39 GPa, 4.91 GPa and 1.36 GPa, respectively.

Fig. 3 shows isolines for equivalent stresses in the matrix under the conditions of fitting into rings and loading with operating pressure (the value "1" corresponds to the failure). The S-point in the matrix recess should be recognized to be the most unsafe under loading and unloading. This conclusion corresponds to the data obtained when analyzing the most frequent cases of matrix failure in experiments. In some cases, however, the matrix failure occurs in the region of A- and G-points, though the safety factor under single loading for these points is considerably higher than that for the S-point. Therefore, additional estimation of the matrix strength under multiple

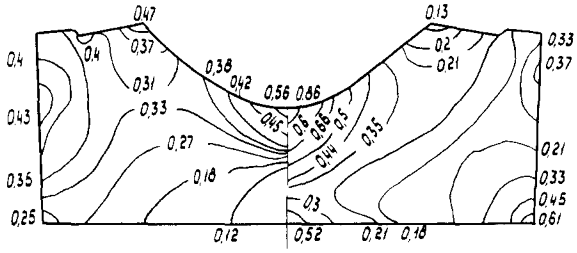

Fig. 3. Isolines of equivalent stresses in the matrix under conditions of (a) fitting rings into the block and (b) loading with operating pressure.

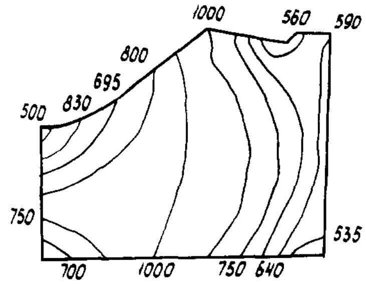

Fig. 4. Isolines for loading cycles.

loading is necessary. Here the durability, i.e. the number of loading cycles to failure can be used as its criterion.

Assume the stress changes at each point of the matrix volume to be cyclic. Considering the line section to be limited in the stress space by the ends of the stress vectors in the state subsequent to fitting and under operating loading we find the durability criterion for hard alloy matrix [7]:

$$\frac{|\bar{\sigma}_a|}{|\bar{\sigma}_+|} = \left(1 - \frac{|\bar{\sigma}_m|}{|\bar{\sigma}_+|}\eta\right) Q(N_1) ;$$

$$\frac{|\bar{\sigma}_a|}{|\bar{\sigma}_-|} = \left(1 + \frac{|\bar{\sigma}_m|}{|\bar{\sigma}_-|}\eta\right) Q(N_2) . \qquad (1)$$

Here, $\bar{\sigma}_a$ and $\bar{\sigma}_m$ are, the vectors of amplitude and average stresses, respectively. $|\bar{A}| = (\bar{A} \cdot \bar{A})^{1/2}$, $|\bar{\sigma}_+|$ and $|\bar{\sigma}_-|$ are the ultimate static strengths for the two types of stressed state corresponding to the line considered;

$$\eta = (\bar{\sigma}_+ \cdot \bar{\sigma}_m) / |\bar{\sigma}_+ \cdot \bar{\sigma}_m|$$

is the parameter which takes into account the direction of the $\bar{\sigma}_m$ vector; $Q(N) = 1 - 0.11 \lg N$ (for BK-6 alloy). From the two equations in eq. (1) we obtain two values N_1 and N_2 for each point of the matrix volume, the minimum one corresponds to the estimated value for the number of loading cycles N to failure. The results of the calculation are shown in fig. 4 as durability isolines.

The most probable location of failure fits the S-point ($N = 490$). Note the conditionality of the number given which is obtained from the calculation example. If the failure at this point does not occur due to local strengthening or due to the effect of other unaccounted factors, then the points G ($N = 530$) and A ($N = 550$) appear to be weak. This conclusion, drawn from the example of calculation, corresponds to the types of matrix failure observed experimentally.

The above method of durability calculation makes it possible to determine correctly the most probable locations of failure. The efficiency of the calculation procedure is testified to the satisfactory agreement of the calculated results with the known experimental data [8] on the volume dependence of durability for geometrically similar matrices.

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