FEATURES OF OPTIMIZATION OF PRESSING MODES OF POWDER MATERIALS FOR PARTS OF SHIP MECHANISMS

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Abstract

The article considers the features of optimization of modes of pressing powder materials for ship machinery parts using mathematical models. It is established that in order to obtain an adequate mathematical model, it is necessary to more accurately specify the rheological properties of powder materials, which largely determine the kinetics of compaction during HIP.
It is indicated that the solution of this problem by the finite element method for products of complex configuration with nonlinearity of the used relations and non-stationary nature of deformation requires the use of iterative procedures in the presence of a large number of finite elements at each time step.
It is determined that the upper-level model does not allow solving the problems of optimization and optimal control of the HIP pressing process. To overcome these difficulties, it is possible to use the lower level of modeling, including zero-dimensional and one-dimensional HIP models.
A system of technological modes of hot isostatic pressing of powder materials is proposed, which provides for discrete and continuous mathematical modeling of HIP. Discrete and continuous representation of the HIP technological process design system structurally includes the interaction of mathematical models of the upper and lower levels.
The use of lower-level models with the use of an optimization apparatus allows us to seriously narrow the search area for technological solutions, thereby obtaining the most reliable and accelerated information on the modes of pressing powder materials for parts of ship mechanisms.

Keywords: optimization, pressing modes, powder materials, mathematical models

I. Introduction

It is indicated that HIP is usually used for powder materials of relatively high cost, i.e. alloy steels, therefore, it is important to determine the optimal pressing conditions that provide the required level of physical and mechanical properties at minimal costs [4-6].

In this regard, the most important tasks are the design of a press mold for HIP in order to obtain a semi-finished product that is closest to the required product, as well as the determination of HIP modes to achieve the required level of properties in semi-finished products [3-5].

One of the ways to solve this problem is to develop a system for designing GIP process modes based on an adequate mathematical description of the object under study [6-8].

Analysis of literature data allows us to conclude that there are two main directions in mathematical modeling of GIP of powder materials: discrete and continuous. The first direction [3-5] considers the deformable body as a set of individual incompressible particles with a pore volume between them that changes as they compact.

The second direction [1-4], based on the phenomenological approach, considers the deformable body as a whole, endowing it with the ability to plastically change not only its shape but also its volume. In discrete theories, the system of equations for describing one-dimensional distributions of density, temperature, etc. can be generally represented as follows:

$$\frac{dD}{dt} = K_D \cdot f(D) \tag{1}$$

kinetic equation of compaction ($D-$ relative density; $K_D -$ kinetic constant of compaction);

$$\rho_S \cdot D \cdot C_p \frac{d\theta}{dt} = div(\lambda qrad\theta) \tag{2}$$

heat conductivity equation ($\rho_S -$ density in compact state, C-heat capacity, $\theta -$ temperature, $\lambda -$ thermal conductivity coefficient; $\lambda = \lambda(\theta D) -$ given function);

$$div\, v = -\frac{1}{D}\frac{dD}{dt} - \tag{3}$$

continuity equation ($v -$ speed).

This system is supplemented by a boundary condition

$$v_r /_{r=0} = 0 \tag{4}$$

and also the ratios

$$\rho_S = \rho_e(t) \text{ and } \theta_S = \theta_e(t) \tag{4'}$$

where $\rho_e(t)$ and $\theta_e(t) -$ are the functions specified by the pressing cycle.

Equation (1), depending on the functions included in it, describes various compaction mechanisms; diffusion through the grain body and along their boundaries to isolated pores, and a number of others.

Compaction from instantaneous plastic deformation can be calculated using fairly simple relationships (3) and obtain starting density values, from which the compaction process itself begins, depending on time. In this case, the overall compaction rate is the sum of the components from its individual mechanisms.

II. Purpose of the work

The aim of the work is to identify the features of technological modes of hot isostatic pressing of powder materials used for the manufacture of parts of ship mechanisms.

III. The object of the study

The object of the study is the technological modes of hot isostatic pressing of powder materials, and the subject of the study is mathematical models obtained using the finite element method for isostatic pressing of powder products of ship mechanisms.

IV. Equations of the process of pressing powder materials

It should be noted that the discrete theories used to describe the processes of deformation of powder products have a significant drawback. They make it difficult to describe the process of pressing at arbitrary points of bodies of complex configuration, which significantly distorts the uniformity of compaction. However, these problems can be successfully solved by using the apparatus of continuum mechanics.

Let us consider in general terms a system of equations describing the non-isothermal flow of a viscoplastic isotropic compressible material with strain hardening.

Equilibrium equation [7]:

$$div T_\sigma = 0 \tag{5}$$

where $T_\sigma -$ is the stress tensor;

$$T_\xi = \frac{1}{2}(qrad\ \vec{v} + qrad^T \vec{v}) \tag{6}$$

Kinematic relations:

$$\frac{d \ln \rho}{dt} + div\,\vec{v} = 0 \tag{7}$$

where $T_\xi -$ is the strain rate tensor;

Continuity equation, defining relations [8]:

$$D_\sigma = 2\mu D, \quad \sigma_0 = 3R\xi_0 \tag{8}$$

where $D_\sigma -$is the stress deviator; $D_\xi -$ the strain rate deviator; $\sigma_0 -$ the average stress; $\xi_0 -$the average strain rate, $\mu, R -$ the coefficients of shear and bulk viscosity.

Heat equation [9]:

$$c \cdot \rho \cdot \frac{d\theta}{dt} = div(\pi \cdot qrad\theta) + \nu \cdot T_\sigma \cdot T_\xi \tag{9}$$

where ν - is the coefficient of conversion to mechanical work.

Note that the coefficients of shear 2μ and bulk 3R viscosity included in the defining relations can be established experimentally. In this case, the concepts of creep potential Φ and loading surface F are used. In our case, we assume

$$F = F(T, \sigma_0, \sigma_\rho, x_i) = 0 \tag{10}$$

where T - is the intensity of tangential stresses, a and x_i refers to the hardening parameters, the environments of which can be deformation and speed.

The solution of equations (5) - (9) with boundary conditions (4') makes it possible to construct kinematic, force and temperature distributions in a deformable body. Based on the use of discrete and continuous representations, a design system for HIP technology is proposed, structurally including the interaction of mathematical models of the upper and lower levels.

The top-level model is a solution using the finite element method (FEM) of the system of equations (5) - (9). To obtain a system of nonlinear equations dependent on time, the weighted residual method [9-10] was used.

V. Algorithm for solving the problem

Let us consider the algorithm for solving the problem when creating a top-level model. In this case, the time axis is divided into intervals or time steps. In each such interval, the quantities that depend on time are assumed to be constant. The problem is reduced to solving a nonlinear system of equations at each time step. For this purpose, the method of simple iterations is used, which reduces the solution of a nonlinear system to a multiple solution of a linear system of equations. When the convergence of the iteration cycle is achieved, the period to the next time interval passes.

It should be noted that the applied solution algorithm is traditional and is described in detail in a number of fundamental works [3,5]. Let us dwell in more detail on some of the details that distinguish this implementation from a number of similar studies.

To divide the time axis into intervals, an algorithm for automatic adaptation of the time step is used. The need to use such an algorithm follows from the duration of the modeled process and the desire to obtain sufficiently accurate solutions with reasonable costs of machine time.

The essence of the algorithm is that the time step value is selected depending on the speed of change of the solution over time. This algorithm limits the change of the solution in the time interval, allowing to consider the moments of the fastest changes of the process parameters. When the process reaches the stationary stage, the time step increases sharply, thereby increasing the overall efficiency of the calculation.

VI. Discussion of results

For the model under consideration to function, it is necessary to specify the rheological properties of the deformed medium and the shell material. At the first stages of the HIP process, the main influence on the onset of plastic deformations of the mold-powder system is exerted by the mold itself, which is determined by the level of the mechanical properties of the material. Accurate knowledge of the rheological properties of the shell material is of great importance for an adequate description of the HIP process at its initial and subsequent stages.

Rheological properties of stainless steel 12X18H10T, widely used for manufacturing press molds, were determined. Experiments were conducted on pressing cylindrical samples $d = 9$ and $l = 14\ mm$ in the following temperature-speed modes: mm/min. The specified values for the given sample sizes gave an initial deformation rate in the range of $6{,}2{\cdot}10^{-5}$-$1{,}2{\cdot}10^{-1}$ c^{-1}, which corresponds to the real parameters of the HIP.

Fig. 1 shows the dependences of the yield strength on the test temperature at different initial deformation rates, and Fig. 2 and 3 show the hardening curves at different values of temperature and deformation rates. The general course of the curves is quite traditional, but their value is determined by the comparatively low values of the speed parameters.

Mathematical processing of the test results allowed them to be presented in the form

$$T = \tau_S(1 + \alpha H^{\beta} + \gamma L^{\delta}) \cdot e^{R\theta} \tag{11}$$

where H- is the intensity of deformation rates; L- is the degree of deformation; τ_S-is the yield strength for shear. This equation was later used in the complex of programs for the HIP process. For stainless steel grade 12X18H10T, the coefficients in formula (11) have the following values: $\tau_S = 802{,}5$ MPa; $\alpha = 4{,}8$; $\beta = 0{,}5$; $\gamma = 11{,}1$; $\delta = 0{,}75$; $R = -0{,}003$.

The upper-level model describes the rheological properties of a deformable medium under the ellipsoidal plasticity condition and will be discussed in more detail in the next publication when compiling the lower-level model.

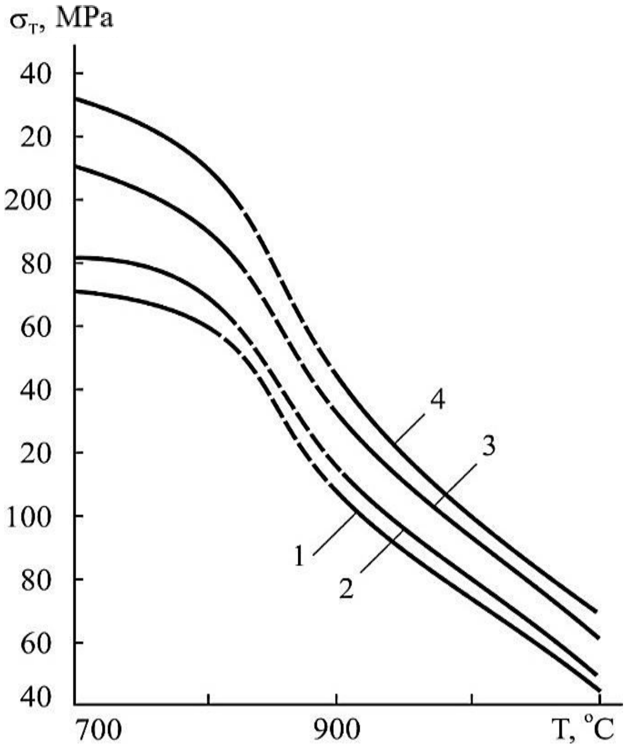

Figure 1: *Dependence of the yield strength of 12X18H10T steel on temperature at deformation rate $6{,}2{\cdot}10^{-5}$ (1), $1{,}2{\cdot}10^{-4}$ (2), $6{,}2{\cdot}10^{-4}$ (3), $1{,}2{\cdot}10^{-3}c^{-1}$ (4)*

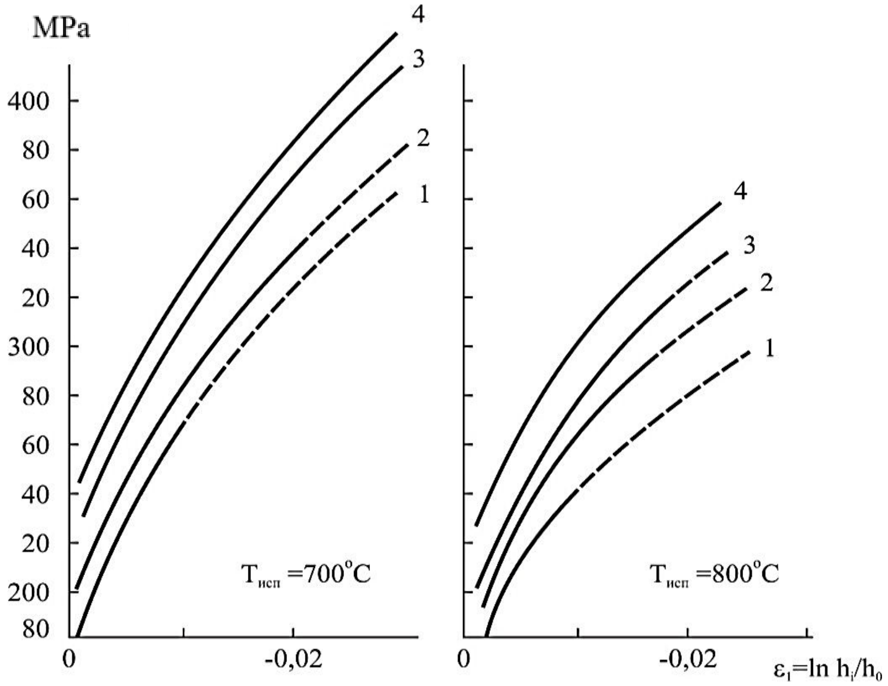

Figure 2: *Hardening curves of 12X18H10T steel at a deformation rate of 0.05 mm/min (1), 0,1 (2), 0,5 (3), 1,0 mm/min (4)*

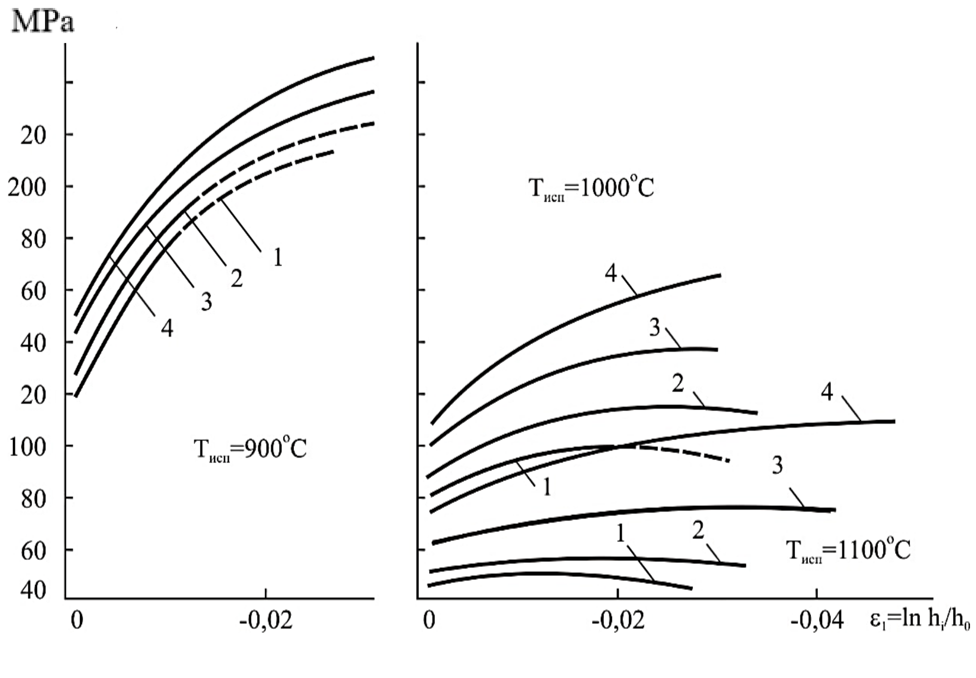

Figure 3: *Hardening curves of 12X18H10T steel at deformation rates of 0,05 (1), 0,1 (2), 0,5 (3), 1,0 mm/min (4)*

VII. Conclusion

Thus, to obtain an adequate mathematical model, it is necessary to more accurately specify the rheological properties of powder materials, which largely determine the compaction kinetics during HIP. The solution of this problem by the finite element method for products of complex configuration with nonlinearity of the used relationships and non-stationary nature of deformation requires the use of iterative procedures in the presence of a large number of finite elements at each time step.

Therefore, the upper-level model does not allow solving the problems of optimization and optimal control of the HIP pressing process. To overcome these difficulties, it is possible to use the lower modeling level, including zero-dimensional and one-dimensional. HIP models.

A system of technological modes of hot isostatic pressing of powder materials is proposed, which provides for discrete and continuous mathematical modeling of HIP. Discrete and continuous representation of the HIP technological process design system structurally includes the interaction of upper and lower level mathematical models.

When using the upper-level model to obtain an adequate mathematical description, it is necessary to know the rheological properties as accurately as possible, mainly determining the compaction kinetics during HIP. This problem can be solved by the finite element method for products of complex configuration.

To overcome the difficulties associated with the use of the upper-level model, it is necessary to apply the lower modeling level, including zero-dimensional and one-dimensional HIP models. In this case, under conditions of all-round compression, the stress, strain and strain rate tensors are spherical tensors.

Within the framework of the proposed system, the upper-level model can be used in a dialog mode, allowing, by specifying the initial data of the HIP process, to obtain complete information on its progress and results, and, if necessary, to correct one's actions. The use of lower-level models with the use of the optimization apparatus allows one to significantly narrow the search area for technological solutions, thereby obtaining the most reliable and accelerated information.

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