

ABOUT THE VOLUME FORMING OF ALUMINIUM DETAILS IN SUPERPLASTICITY CONDITIONS

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Abstract

The problem of creation of technological approaches to research of processes of volume forming of industrial aluminum alloys on the basis of managed superplasticity deformation is considered. The research is carried out within the dynamic model which with use of equations the elasto-plastic processes of small curvature is generalized on a spatial case. Isothermal conditions in the temperature ranges of superplasticity allow to consider responsibility for the process in the field of the deformation rate. The received rate restrictions open opportunity thus to allocate and mathematically to limit area in the center of plastic deformation in which the effect of superplasticity is realized. This area in which in the course of dynamic recrystallization the ultrafine-grained structure was created, borders on zones of thermoplasticity and high-temperature creep. So there is solved the problem - to manage in the course of heating and deformation by the grain size. Therefore, the main problem of creation of mathematical model of process of forming is the definition and the solution of the corresponding regional task. Need to maximize the volume of a zone of superplasticity at an optimum combination of power power, thermal and kinematic conditions and, naturally, to predict receiving details with ultrafine-grained structure appears the general here. Analytical research of the forming process of a thin-sheet aluminum semi-finished product is given as an example from an alloy 1561.

Keywords: Superplasticity, managed superplasticity deformation, aluminum alloy 1561

1. INTRODUCTION

We will consider a problem of creation technological approaches to research of processes of volume forming of industrial aluminum alloys on the basis of managed superplastic deformation [1].

The mathematical formulation and the exact solution of technological problems with use of superplasticity are interfaced to serious difficulties. In concrete technological processes, first of all, volume deformation superplasticity existence in the deformation center can be established only indirectly. Moreover, the deformation center doesn't manage to be transferred completely, as a rule, to a superplastic state because of strong heterogeneity of fields of temperatures and deformation speeds. Isothermal conditions in optimum for superplasticity a temperature range entering certain simplifications as responsibility for implementation of the effect is shifted on the field of deformation speeds. Thus in compliance with high-speed restrictions in the deformation center there are boundary regions of superplasticity of a zone of thermoplasticity and high-temperature creep. The last emphasizes complexity of physical processes in the deformation center and, thereof, a variety of the parameters characterizing mechanical properties of materials [2].

2. MATERIALS AND METHODS. GOVERNING EQUATIONS

Object of research are industrial aluminum alloys in the initial deformed or cast states. It means that superplasticity of dynamic type is realized. The research is based on experimental and theoretical results presented in [1]. Here on the basis of mechanical experiments with metallographic confirmation it is noted that transition of aluminum alloys to a superplastic state is connected with structural transformation by dynamic recrystallization [3]. It is obvious that the hierarchy of structural states, characteristic for the systems staying

far from thermodynamic balance is peculiar to aluminum alloys. For modeling of such nonequilibrium processes synergetic approach [2] is involved. Within offered approach for the description of experimental data on high-temperature deformation in the extensive high-speed range of industrial aluminum alloys the mathematical apparatus of the accidents theory is involved, in particular, the potential of accident of assembly. The operating parameter of potential is defined by the corresponding kinetic equation. During reduction of experimental data to a canonical form of the accident two alternative internal parameters condition for which stay the evolutionary equations are also offered are come into. Compliance of model to experimental results of stretching and compression of group of industrial aluminum alloys is established by a task of material function of sensitivity of the environment to structural transformations and definition of four material constants.

Generalization [1] on a spatial case of experimental data is based on the standard representation that the plastic current in metals is described within the theory the elasto-plastic processes of small curvature in rather extensive range of change of temperature and deformation speeds [4, 5], making the mathematical base at research of technological processing of metals by pressure. Feature of this theory consists in that it obligatory requires using of the state equation which of is come from a condition of balance of potential of accident of assembly. In this case stress intensity is function not only deformation speeds intensity, but also temperature, operating parameters and internal state parameters.

On the basis of the told we will formulate the regional task modeling isothermal forming process in which the operating and the internal state parameters are considered as material constants.

So, we have

- differential balance equations

$$\sigma_{ij,j} + F_i = 0; \quad (1)$$

- kinematic equations establishing dependence between components of a tensor of deformation speeds and a vector of movement speeds

$$\dot{\epsilon}_{ij} = \frac{1}{2}(u_{i,j} + u_{j,i}); \quad (2)$$

- incompressibility condition in speeds

$$\dot{\epsilon}_{ii} = 0; \quad (3)$$

- theory the elasto-plastic processes of small curvature equations

$$\sigma_{ij} - \delta_{ij}\sigma_0 = \frac{2\sigma}{3\dot{\epsilon}}\dot{\epsilon}_{ij}; \quad (4)$$

- the state equation as

$$\sigma = \sigma^* \left[1 + m_0 \left(\frac{\dot{\epsilon}}{\dot{\epsilon}^*} - 1 \right)^3 + \beta \left(\frac{\dot{\epsilon}}{\dot{\epsilon}^*} - 1 \right) \right]; \quad (5)$$

- static boundary conditions

$$X_{vj} = \sigma_{ij}l_j; \quad (6)$$

- friction condition on a contact surface

$$\tau_k = -\chi\tau_{\max}. \quad (7)$$

Here σ_{ij} , $\dot{\epsilon}_{ij}$ - components of stress and deformation speeds tensors respectively; u_j - a component of a vector of movement speed; σ_0 - average stress; σ , $\dot{\epsilon}$ - intensity of stress and deformation speeds respectively; β - the operating parameter; σ^* , $\dot{\epsilon}^*$ - alternative internal state parameters (accepted as it is stated above, as constants); X_{vj} - components of external influences; l_j - directing cosines of a normal to a contact surface; τ_k - intensity of shifting forces on a surface of the matrix contacting to a deformable material; τ_{\max} - the maximum tangent stress; χ - the proportionality coefficient, which experimental definition by [6].

We will specify that restriction is imposed on the high-speed superplasticity range

$$1 - \left(-\frac{\beta}{3m_0}\right)^{1/2} \leq \dot{\epsilon} \leq 1 + \left(-\frac{\beta}{3m_0}\right)^{1/2}, \quad (8)$$

and, as well as above, β - the operating parameter which is function of temperature (at superplasticity of $\beta < 0$), m_0 - const.

Introduction of criterion (8) allows to prepare the deformation center, having separated from borderlines area of superplasticity in which, following (3), the equiaxial ultrafine-grained structure with a size of grain 1-10 μm was created.

With involvement of system equations (1)-(8) process of low-speed longitudinal rolling of aluminum sheet in isothermal conditions is analytically researched, the optimum combination of power power and kinematic parameters has to lead to formation in the pro-deformed metal of the optimum structure close to the ultrafine-grain.

It is considered that the deformation center responds to change of power, thermal and kinematic parameters of process by change of volume and an arrangement of area of superplasticity which as was already approved, makes part of the deformation center. In other words, at such approach the optimizing task which divides into two parts can be set. In the first of them conditions under which the volume of a zone of superplasticity will be maximum are subject to definition. The second party of a task consists in providing an optimum arrangement of the specified zone in the deformation center.

We will consider process temperature of the chosen optimum realization of effect of superplasticity not leaving for the thermal range. Having excluded temperature, we will pay attention to the analysis of a speeds deformation field as which external characteristic average speed v_0 (an operating variable [7]) on an entrance to the deformation center can serve.

Without stopping in detail on process of the solution of an objective, we will note some important results.

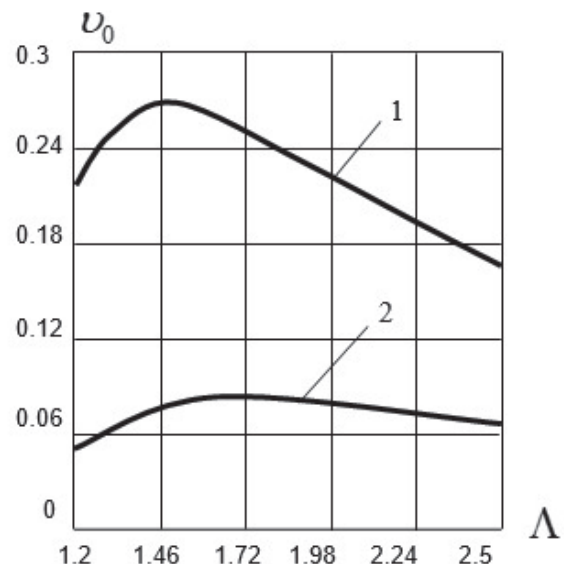


Fig. 1 Dependence of speed of giving of a material in rolls v_0 from the sheet sinking extent Λ : 1 - out of a high-speed superplasticity range; 2 - in high-speed superplasticity conditions

There are dependences of speed of giving of a material in rolls v_0 from the sheet sinking extent Λ given in the **Fig. 1**. Calculations are carried out for alloy AlMg5 at the following parameters of the material: $m_0 = 0.3333$; $\beta = (-0.04957)$, $\chi = 0.3$ and geometrical parameters of process - leaf thickness at the exit from rolls of 0.01 m, sinking extent $\Lambda = 1.3-2.5$; rolls radius $R = 0.11$ m.

From schedules in **Fig. 1** it is visible that at small Λ values the speed v_0 is rather high, and since some value Λ , stable insignificant decrease in speed v_0 is noted.

There are curves of change of pressure upon rolls depending on the contact parameter ρ at the characteristics of process entered above are given in the **Fig. 2**. It is shown that superplasticity use sharply reduces the size of pressure upon rolls. We will note that qualitatively this result doesn't contradict [8].

3. EXPERIMENTAL RESULTS

For an assessment of possibility of optimization of temperature and high-speed parameters in volume technologies process of hot longitudinal rolling of sheets of a cast aluminum alloy 1561 [1] is realized. The choice of optimum thermomechanical conditions was based on experimental data on standard specimen compression. Rolling was made in isothermal conditions on a low-speed laboratory camp on cards in size of 0.24 x 0.12 x 0.04 m. Cards were rolled fractionally with total relative sinking extent on height 64-65%.

The rolling process was researched in three modes. Modes I and II corresponded to conditions of standard industrial technology and superplasticity. In the I-II mode rolling was carried out in the beginning on standard, and then transition to superplasticity conditions was made. Main parameters of rolling process of experimental cards are specified in the **Table 1**.

Mechanical properties of the rolled alloy at a normal temperature were compared to characteristics of a sheet of 1561 alloy similar thickness of industrial supplying. There are results of tests presented in the **Table 2**.

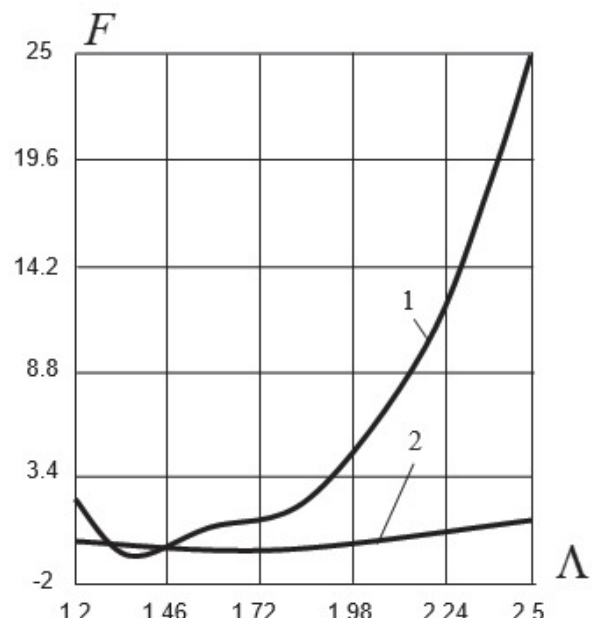


Fig. 2 Dependence of the deforming force F from the sheet sinking extent Λ : 1 - out of a high-speed superplasticity range; 2 - in high-speed superplasticity conditions

Table 1 Mechanical properties of researched specimen of sheet hire

Heating mode for rolling	$\sigma_{0.2}$, MPa	σ_u , MPa	δ , %	Noting
OST 1.92073-82	180	340	12	Without heat treatment; for sheets thickness $(5-10) \times 10^{-3}$ m
Standard	206	358	15.4	Hot rolling for 17 cycles at a temperature 733 K
I - II	175	325	22.2	Rolling in the conditions of superplastic deformation
II	226	384	20.5	Rolling in the conditions of superplastic deformation

Table 2 Main parameters of the rolling process of experimental cards

Heating mode for rolling	Heating temperature, K	Metal temperature, K	Extent of deformation for cycle, %	Strip thickness, m·10 ⁻²		Number of cycles	Deformation speed for a cycle, s ⁻¹ 10 ⁻²	Pressure of metal upon rolls, kN	Specimen type and type rolling tests
				the initial	the final				
I	693	643-691 665	3.60-4.97 4.3	4.0	2.7	9	3.09-3.55 3.2	72.6-112.7 93.0	Without mechanical tests
I-II	793	656-770 713	1.72-3.22 2.5	2.7	1.4	27	2.35-3.42 3.2	21.1-96.1 63.0	Flat
II	793	653-773 723	1.6-4.88 3.07	4.1	1.39	37	2.6-4.0 3.15	36.0-86.0 61.0	Flat and round
I	693	-	1.44-4.7 3.07	4.0	1.37	35	1.87-4.13	-	Without mechanical tests
Standard	733	-	25.0-33.0 30.2	4.0	1.35	3	10	-	Round

Noting: In numerator are provided limit, and in a denominator - average parameters of rolling.

It is known [1] that to superplasticity of aluminum alloys there correspond emergence and preservation in metal structure of the equiaxial fine grain which is inevitably leading to essential decrease in anisotropy of mechanical properties. For experimental check of the fact of approach of a mode II to superplasticity tests the Gagarin's specimen which have been cut out from a leaf in the longitudinal and cross directions (**Table 3**) were carried out. The obtained data specify that the semi-finished products rolled in the conditions of superplasticity, possess the minimum anisotropy of mechanical properties.

Table 3 Average values of mechanical characteristics of an alloy 1561, received by rolling on a mode II

Direction of specimen cutting	$\sigma_{0.2}$, MPa	σ_u , MPa	δ , %
Longitudinal	164	350	21.6
Cross	168	330	15.3

CONCLUSION

The offered system of the equations (1)-(8) can be used for statement and the solution of problems of volume forming as allows to allocate and mathematically to limit in the deformation center a superplasticity zone. Therefore, opportunity to operate in the process of heating and deformation by the size of grain and to predict production of semi-finished products with beforehand set properties, for example, with ultrafine-grained structure opens. This research is added with the analytical analysis of operation of longitudinal rolling of a thin-sheet aluminum alloy. The example of rolling of a thin sheet from an alloy 1561 in an initial cast state is given, and, comparison of results with the standard technologies, showing is made that with approach to superplasticity modes deformation anisotropy considerably decreases.

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