SOME SPECIFIC FEATURES OF HIGH-TEMPERATURE DEFORMATION OF MATERIALS

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Experimental results for high-temperature deformation of an iron-based structural material in the temperature ranges including the points of the $\text{Fe}_\alpha \rightarrow \text{Fe}_\beta \rightarrow \text{Fe}_\gamma$ transition are given. It is shown that the strain-strength properties of the material change nonmonotonically on the interval $700^\circ C < T < 1000^\circ C$ and that the internal phase-structural changes exert an effect on the thermal effects. Approximating dependences that permit one to describe deformation processes in the indicated temperature ranges upon uniaxial loading are proposed.

The temperature intervals of the operational modes of structural units are usually established in such a way that the material in these ranges is structurally stable. A deliberate or unexpected increase in temperature can lead to a change in the internal state of the material and the need to consider the high-temperature deformation process under external thermal effects with allowance for internal phase-structural changes. The specific features of the deformation behavior of materials in the temperature ranges of structural instability are of interest from two viewpoints, namely, in solving technological problems on pressure treatment of materials in a slow temperature-force regime of deformation, including superplasticity regimes, and in assessing the serviceability of multipurpose structural units in an emergency.

In [1], referring to a VT-20 titanium alloy, the authors considered the features of high-temperature deformation of structural materials for which if even internal transformations occurred, their influence was insignificant, and the monotone change of the strain-strength characteristics was observed in the macroscopic ratio. The experimental results obtained under stationary and nonstationary thermal-force conditions in the temperature range of $700^\circ C < T < 950^\circ C$ were rather close, which allowed us to determine the characteristics of similar materials and to solve applied problems for the indicated temperature interval in an “uncoupled” formulation.

In the present study, using an VL-1D iron-based structural alloy as the example, we consider the specific features of high-temperature deformation of materials in which the internal structural changes affect greatly the physicomechanical properties. In the macroscopic ratio, this is manifested as an abrupt nonmonotone change in the characteristics of the material in the temperatures range of structural transformations. For these materials, in the above-mentioned temperatures ranges, the results of deformation experiments in stationary and nonstationary conditions are not comparable; therefore, one cannot solve applied problems omitting the processes of loading. In the methodical aspect, the present study is a continuation of [1].

Figure 1 shows results of the stationary creep experiments of VL-1D for fixed values of the voltage $\sigma$ and temperature $T$ in the form of a creep strain rate versus voltage. Diagrams 1–7 correspond to experimental temperatures of 700, 900, 910, 930, 950, 1000, and $1100^\circ C$. The tension experiments were performed on cylindrical specimens with the working-section length $l = 50$ mm and the diameter $d = 10$ mm; the specimens were fabricated from a material in a condition of delivery without any preliminary thermomechanical treatment.
To maintain the constant \( \sigma \) in the course of the experiment, the load was corrected. Several experiments were carried out at constant temperature with a stepwise variation in voltage with overloading intervals equal to 20–30 min. At each stage of loading, the strain rate was determined. Some of the experiments were free from overloading up to failure to determine the strain values at the moment of creep transition to the third stage and the strain value at the moment of failure. For both types of experiments, the rate of creep strain was the same on the linear sections of the diagrams.

In the temperature intervals below 770\(^\circ\)C and above 900\(^\circ\)C, the diagrams in Fig. 1 are qualitatively similar to those for VT-20 [1], which makes it possible to use the same approximation for these temperature intervals in the description of deformation processes \( \dot{\varepsilon}^c = \varphi(\sigma, T) \) as that in [1]:

\[
\dot{\varepsilon}^c = K \exp \left( A(T) + B(T)\dot{\varepsilon} + C(T) / \dot{\varepsilon} \right),
\]

Here \( a_j, b_j, \text{ and } c_j \) are constants, \( \dot{\varepsilon} = \sigma / 10^{-1} \text{ MPa}, \dot{T} = T / 10^{-2} \text{ } ^\circ\text{C}, \text{ and } K = 1 \text{ sec}^{-1} \) (hereinafter, in describing the dependence (1), the bars above \( \dot{\varepsilon} \) and \( T \) are omitted). All the coefficients in (1) are determined with the use of the experimental data on tension at fixed \( \sigma \) and \( T \). For example, at \( T \geq 900\text{ } ^\circ\text{C} \), they have the following values:

\[
\begin{align*}
a_0 &= -39.595, \\
a_1 &= 3.0347, \\
a_2 &= -0.050806, \\
b_0 &= -48.104, \\
b_1 &= 9.3778, \\
b_2 &= -0.43918, \\
c_0 &= 1.552, \\
c_1 &= -1.7971, \\
c_2 &= 0.14123.
\end{align*}
\]

The solid curves in Fig. 1 refer to the dependences \( \dot{\varepsilon}^c = \varphi(\sigma, T) \) calculated by means of the dependence (1) with the values of the coefficients given in (2), and the points refer to the experiment. Figure 2 shows the experimental (points) and calculated, from the dependence (1) (curve 1), values of \( \varepsilon^c(t) \) for varied values of the voltage \( \sigma(t) \) (curve 2) and temperature \( T(t) \) (curve 3). Thus, in this temperature range, the description of the deformation process by the dependence (1) with the characteristics (2) determined from the experiments for fixed \( \sigma \) and \( T \) is also in satisfactory agreement with nonstationary processes. In the field of temperatures below 770\(^\circ\)C, the results are similar.

The situation is different both in the qualitative and quantitative aspects in the temperature interval 770\(^\circ\)C < \( T < 900\text{ } ^\circ\text{C} \). This interval is marked by dashed curves in Fig. 1. As is known, the temperature \( T = 768\text{ } ^\circ\text{C} \) is the point of the phase transition \( \text{Fe}_{\alpha} \rightarrow \text{Fe}_{\beta} \), and \( T = 910\text{ } ^\circ\text{C} \) is the point of the phase transition \( \text{Fe}_{\beta} \rightarrow \text{Fe}_{\gamma} \). If the strength of the iron-based alloy considered decreases monotonically in temperature regions below 768\(^\circ\)C and above 900\(^\circ\)C and its plasticity increases monotonically as the temperature rises (which is in accordance with the principles of thermodynamics), the changes in the strength properties in the indicated temperature range have a different character.

Figure 3a shows results of two experiments on torsion of a continuous round rod of working length \( l = 40 \text{ mm} \) and diameter \( d = 20 \text{ mm} \) for a constant strain rate at the characteristic point \( \dot{\varepsilon}^c = \text{const} \) [2]. Curve 1134