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CREEP AND LONG-TERM STRENGTH OF HEAT-RESISTANT STEELS WITH DIFFERENT STRUCTURES WITH THE ACCOUNT TAKEN OF THE TYPE OF STRESS DEVIATOR

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ABSTRACT
The results of the experimental investigations into creep and long-term strength of heat-resistant steels 15Kh2MFA and 15Kh2NMFA in the initial state and after heat-treatment simulating the metal irradiation embrittlement at the end of the product service date under static loading at the complex stress state and at high temperatures are presented. The experimentally substantiated equations of state describing creep and long-term stability of materials taking into account the type of the stress state are derived.

INTRODUCTION
In connection with increased requirements to structural materials, the further progress and refinements of design methods for structural components operating under various conditions of thermomechanical action are of current concern.

The calculations of structural components for creep and long-term strength are usually based on experimental data of the laws of deformation and fracture of the materials with uniaxial tension by the time-invariant load.

The analysis of works reported previously [1-5 et al] convincingly evidences that the processes of plastic deformation and fracture of materials operating under creep conditions essentially depend upon the type of stress deviator, however, the equations of state describing creep and long-term strength of materials are derived and substantiated experimentally with reference to the uniaxial stressed state.

Attempts to extend these equations to the case of a random stress system by introduction of some generalized stresses without allowance for influence of the first tensor invariant and the third stress deviator invariant upon mechanical properties of the material were not always fruitful.

The laws of creep and long-term strength of pearlite steels of different structures (15Kh2MFA and 15Kh2NMFA) are presented, some of which partly illustrated in Fig. 1 and 2.

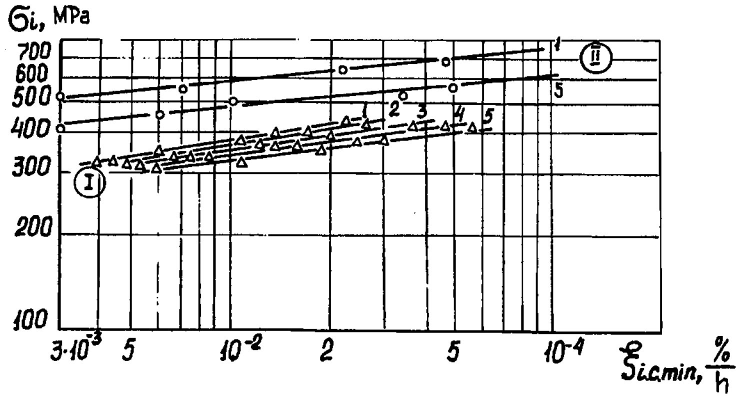

Fig. 1. Creep strain rate minimum intensity dependence on stress intensities for steels 15Kh2MFA in the initial state (I) and after heat treatment 15Kh2HMFA(II) at T = 823 K: $1 - \varphi = 0$; $2 - \varphi = \pi/6$; $3 - \varphi = \pi/4$; $4 - \varphi = \pi/3$; $5 - \varphi = \pi/2$.

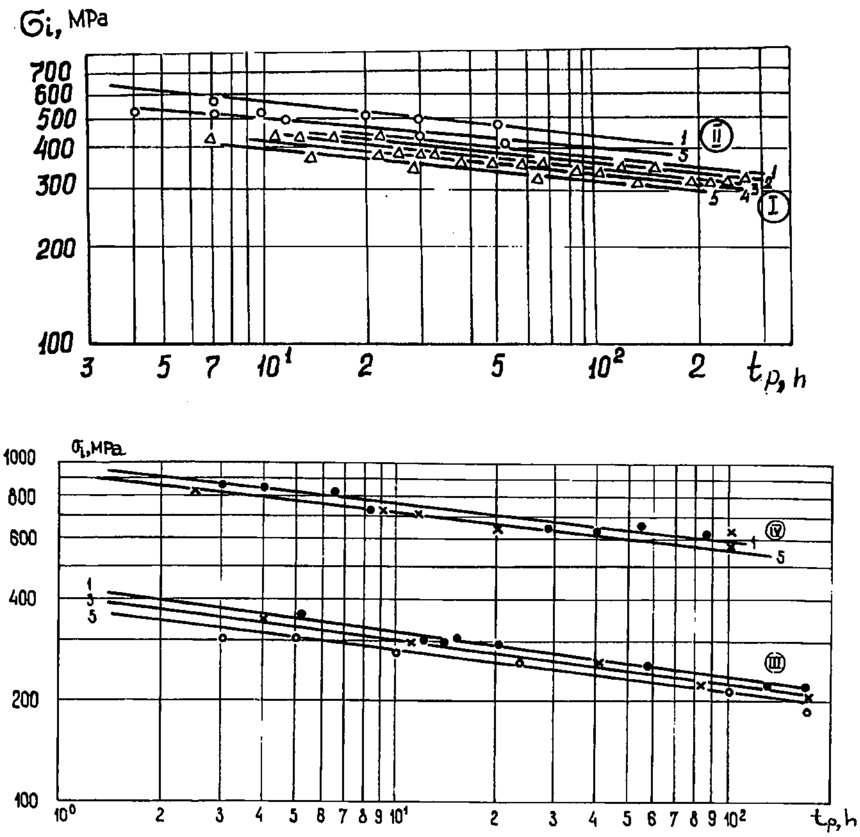

Fig. 2. Long-term strength curves for steels 15Kh2MFA(I) and 15Kh2HMFA(III) in the initial state and 15Kh2MFA(IV) and 15Kh2NMFA (II) after heat treatment at test temperature 823 K: $1 - \varphi = 0$; $2 - \varphi = \pi/6$; $3 - \varphi = \pi/4$; $4 - \varphi = \pi/3$; $5 - \varphi = \pi/2$.

Investigations into creep and long-term strength of the above materials were undertaken on thin-walled tubular specimens subjected to a combined action of a tensile force and a torque under static loading at high constant temperature (T = 823 K) in accordance with a specially developed procedure and a test program in Il'yushin coordinates [7] (Fig. 3) that provides for investigation of the stress state type influence upon plastic straining of materials under conditions of creep with a variation of the parameters φ and σ_i ($\varphi = \mathrm{arctg}\frac{\sqrt{3}\,\tau_{z\theta}}{\sigma_z}$; $-\pi/2 \leq \varphi \leq +\pi/2$).

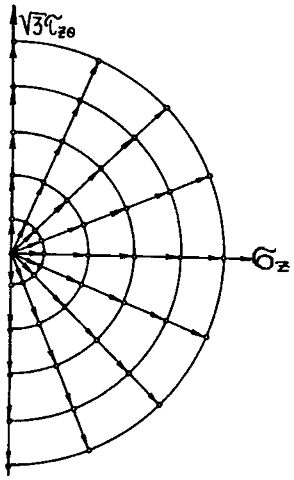

Fig. 3. Test program for thin-walled tubular specimen under complex stress state conditions in Il'yushin coordinates.

The main characteristics in calculations for creep and long-term stability of materials under the complex stress state conditions are the minimum intensity of creep strain rates ξ_{icmin} and the time to fracture t_p [1, 6, 7, 8]. Therefore, an assessment of the stress state type influence upon these characteristics is of practical interest.

Realization of the assigned program for investigation of the above materials has allowed to comprehensively evaluate the influence of the mean stress ($\sigma_0 = \frac{1}{3}\sigma_i \cdot \cos\varphi$) and the third invariant of the stress deviator $J_3(D_\sigma) = 2(1 + 3/2\,\mathrm{tg}^2\varphi)\,/\,27(1 + \mathrm{tg}^2\varphi)^{3/2}$ upon the main characteristics of creep and long-term strength of materials by introduction of an independent parameter specifying the tilt angle of the ray load path.

The relationships shown in Fig. 1, 2 can be described, accordingly, by equations of the form

$$\xi_{icmin}(\sigma_i, \varphi) = B(\varphi)\,\sigma_i^{n(\varphi)}, \tag{1}$$

$$t_p(\sigma_i, \varphi) = A(\varphi)\,\sigma_i^{-m(\varphi)}, \tag{2}$$

where $B(\varphi)$ and $n(\varphi)$ are the parameters specifying the creep capacity of the material, $A(\varphi)$ and $m(\varphi)$ are the parameters specifying the resistance to long-term fracture.

As was shown by investigations into the laws of pearlite steel strain and fracture under creep conditions at the complex stress state, the type of stress state $(-\pi/2 \le \varphi \le +\pi/2)$ has a marked influence upon the main characteristics of creep and long-term strength of the materials studied (the values of B, n, A, m essentially differs from φ parameter specifying the orientation of a loading path).

To estimate the influence of the stress state type upon the creep and long-term strength characteristics of the materials studied, the dimensionless parameters of the form:

$$\frac{B(\varphi)}{B(0)} = \Psi(\varphi); \quad \frac{n(\varphi)}{n(0)} = g(\varphi), \tag{3}$$

$$\frac{A(\varphi)}{A(0)} = \omega(\varphi); \quad \frac{m(\varphi)}{m(0)} = p(\varphi), \tag{4}$$

are introduced, where $B(0)$, $n(0)$, $A(0)$, $m(0)$ are the parameters determined from experiments for creep and long-term strength of materials at the linear stress state, $(\varphi = 0)$; $B(\varphi)$, $n(\varphi)$, $A(\varphi)$, $m(\varphi)$ are that ones determined from experiments at any value of $\varphi\,(-\pi/2 \le \varphi \le +\pi/2)$.

Then, as a result of some transformations, equations (1) and (2) will take the following form:

$$\xi_{icmin}(\sigma_i, \varphi) = B(0)\left\{ \sigma_i^{g(\varphi)} \left[\Psi(\varphi)\right]^{1/n(0)} \right\}^{n(0)}, \tag{5}$$

$$t_p(\sigma_i, \varphi) = A(0)\left\{ \sigma_i^{p(\varphi)} \left[\omega(\varphi)\right]^{-1/m(0)} \right\}^{-m(0)}, \tag{6}$$

where

$$\sigma'_{ef} = \left\{\sigma_i^{g(\varphi)} \left[\Psi(\varphi)\right]^{1/n(0)}\right\}^{n(0)}, \tag{7}$$

$$\sigma''_{ef} = \left\{\sigma_i^{p(\varphi)} \left[\omega(\varphi)\right]^{-1/m(0)}\right\}^{-m(0)} \tag{8}$$

are the effective stresses which the identical values of the minimum intensity of creep strain rate [7] and the time to fracture [8] correspond to, independently from the type of the stress state, as illustrated by Figures 4, 5 presented, in particular, for steels 15Kh2MFA.

$\Psi(\varphi)$, $g(\varphi)$, $\omega(\varphi)$, $p(\varphi)$ parameters are determined from two base experiments, one of which is at the linear stress state $(\varphi = 0)$.

Taking into account the foregoing, equations (7) and (8) can be used as the criterion values when estimating the laws of strain and fracture for the materials studied under conditions of creep and long-term strength at the complex stress state, and equations of state describing the material creep and long-term stability will take the following form:

$$\xi_{icmin}\,[\sigma'_{ef}(\sigma_i\,,\varphi)] = B\,(0)\,\sigma'^{\,n(0)}_{ef}\,, \tag{9}$$

$$t_p\,[\sigma''_{ef}(\sigma_i\,,\varphi)] = A\,(0)\,\sigma''^{\,-m(0)}_{ef} \tag{10}$$

In analyzing the material creep and long-term strength it has been possible to find the correlation relaltionships between parameters included in relevant equations of state which allow to greatly reduce the number of base experiments for receiving the pertinent data about the material. In particular for steel 15Kh2MFA it turned out that $p\,(\varphi) \approx g\,(\varphi)$ and $\omega\,(\varphi)[\Psi\,(\varphi)]^{m(0)/n(0)} \approx 1$. Then we arrive at the following equation:

$$\{\sigma_i^{g(\varphi)}\,[\Psi\,(\varphi)\,]^{\,1/n(0)}\,\}^{n(0)} = \{\sigma_i^{p(\varphi)}\,[\omega\,(\varphi)\,]^{\,-1/m(0)}\,\}^{-m(0)}\,. \tag{11}$$

Consequently, the effective value of stresses calculated from the creep criterion may be employed as a criterion value in assessing the long-term strength of the materials studied.

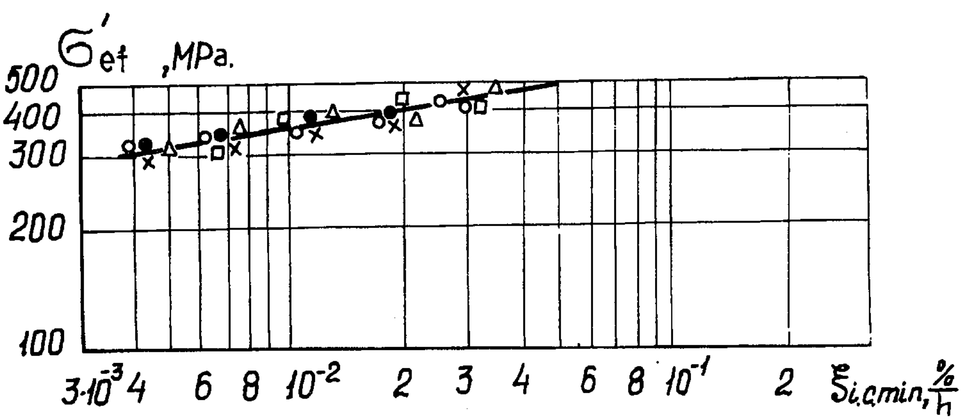

Fig. 4. Generalized dependence of ξ_{icmin} and σ_{ef} for steel 15Kh2MFA at T = 823 K and various values of φ .

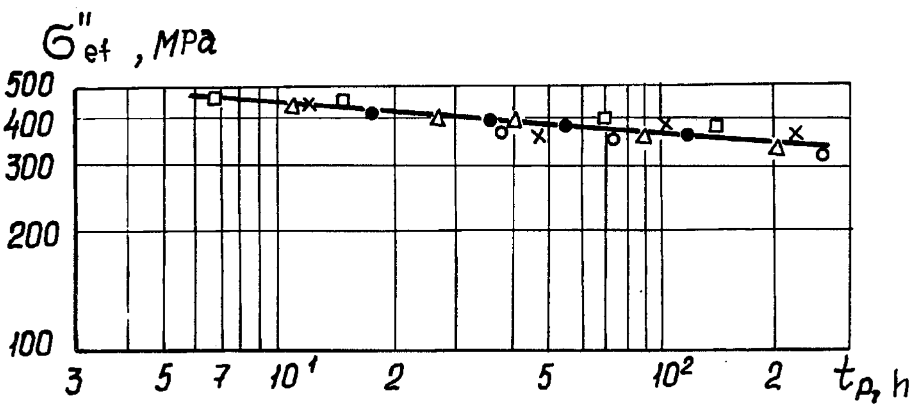

Fig. 5. Generalized dependence upon σ_{ef} for steel 15Kh2MFA at T = 823 K and various values of φ .

Thus, the performed cycle of investigations into creep and long-term strength of materials has allowed to derive equations of state describing creep and long-term strength of materials taking into account the type of the stress state, to establish the correlation relationships between the parameters which specify the material properties in these equations, a result which made it possible to reduce the number of base experiments for receiving the necessary information about the material.

REFERENCES

1. Pisarenko G.S., Lebedev A.A. 1976 Strain and Strength of Materials at Complex Stress State. Kiev: Naukova Dumka.
2. Namestnikov V.S. On the Creep at Complex Stress State. - In the book: Creep and Long-Term Strength. 1963. Novosibirsk, Publishing House of Siberian Division of the Academy of Sciences of USSR, pp. 100-109.
3. Goldenblat I.I., Bazhanov V.L., Kopnov V.A. 1976. Long-Term Strength in Machine Building. Moscow: Mashinostroyenie.
4. Gorev G.V., Rubanov V.V., Sosnin O.V. 1979. On the derivation of creep equations for materials with different tension and compression properties. - Prikladnaya Matematika and Technical Physics. N4, pp. 121-128.
5. Mozharovskaya T.N. 1982. The influence of the third invariant of stresses upon the long-term strength of the material under conditions of plane stress state. - Problemy Prochnosti, N16, pp.53-55.
6. Rabotnov A.A. 1966. Creep of structural components. Moscow: Nauka.
7. Il'yushin A.A. 1948. Plasticity. Moscow: Gostekhizdat.
8. Malinin N.N. 1975. Applied theory of plasticity and creep. Moscow: Mashinostroyenie.