VISCOPLASTIC PROPERTIES OF STEEL 10GN2MFA WITH A COMPLEX STRESSED STATE

F. F. Giginyak, A. A. Lebedev, V. V. Bashta, A. V. Getmanchuk, and V. F. Titov

Results are given for experimental studies of the viscoplastic properties of steel 10GN2MFA with different ratios of principal stresses in the temperature range 20-320°C performed under conditions of stepwise loading. The invariance of the generalized equilibrium deformation curve towards the forms of stressed state and also the material quasiviscosity characteristics towards the form of stressed state and the amount of accumulated irreversible strain for the test material is established by experiment.

In evaluating the cyclic endurance of highly loaded elements of power generating equipment, in particular horizontal steam generator heat transfer headers from a water-cooled power reactor operating under complex conditions of thermal and force loading, it is particularly important to describe the kinetics for achieving the limiting state of the structural metal taking account of a number of factors associated with actual operating conditions and primarily the form of stressed state and temperature. Very promising approaches for this purpose are based on evaluating metal quasiviscous properties caused by rapid effects preceding active deformation using an elastoviscoplastic model [1, 2].

As shown previously [2, 3], for a number of heat-resistant steels based on the results of special tests with certain force regimes it is possible to obtain equilibrium deformation curves physically equal to the deformation curve with a strain rate tending towards zero.

In order to evaluate the validity of the basic hypotheses [1] we consider processes with developed creep strain using the results of studies for certain heat-resistant steels.

Experiments were performed on thin-walled tubular specimens (D/δ = 50) made of steel 10GN2MFA according to the procedure and in equipment described in detail in [4, 5] with principal stress ratios K = a2/a1 = ∞, 2, 1, 0.5 in a regime of proportional stepwise loading. Tests were performed at 20, 285, and 320°C, and here in each step as previously [3] loading was realized in an active deformation regime with a constant intensity for strain rate εᵢ = 0.025%/sec. Then tests were carried out for relaxation until the reduction stress relaxation rate reached a previously established minimum value (the parameter monitored almost ceased to change over a certain time interval), i.e. a state which we call equilibrium or quasiequilibrium. Without unloading a specimen it was transferred to a creep tests keeping it also under load up to an equilibrium condition. After this without unloading testing was repeated for relaxation as previously until an equilibrium condition was reached and then the specimen was unloaded.

Then it was transferred to a new loading stage with a higher level of loading than the previous stage repeating the same sequence for the whole loading operation mentioned. The results of tests were presented in stress and strain intensities.

We evaluate the effect of the form of stressed state on the viscoelastic behavior of the test steel.

Given as examples in Fig. 1 are some deformation curves on coordinates of stress intensity-strain intensity for steel 10GN2MFA obtained from the results of tests under conditions of stepwise loading at room temperature. From the points corresponding to the equilibrium condition quasistatic deformation curves were plotted similar to those obtained in [2, 3]. As for other steels of this class [2, 3], for the test metal with a plane stressed state the same features are observed as under conditions of uniaxial stepwise loading at room temperature.

A series of initial sections of creep curves for the steel in question for some ratios of principal stresses and temperature levels are presented in Fig. 2.

It is noted that the amount of accumulated irreversible strain preceding loss of stability for plastic deformation is different for different forms of stressed state both at room and at elevated temperatures. The minimum value occurs, as for other materials [3], with a principal stress ratio K = 0.5.
Fig. 1. Deformation curves (solid lines) and actual deformation curves 1 plotted from them (broken lines) and also quasistatic (equilibrium) curves 2 (broken-dotted lines) for steel 10GN2MFA with stepwise loading with an original constant active strain rate intensity $\dot{\varepsilon}_1 = 0.025\%$/sec and $T = 20^\circ$C under conditions of a complex stressed state: a) $K = \sigma_2/\sigma_0 = \infty$; b) $K = 1$; c) $K = 0.5$.

Analysis of creep curves in the region of uniform deformation showed that the kinetics of the creep process under these conditions depends markedly on the level or prior irreversible strain and it depends weakly on the form of stressed state in the case of presenting strains in intensities. In evaluating the effect of temperature on development of creep processes it is noted that significant creep was observed at $20^\circ$C, there was much less at $320^\circ$C, and it was almost absent at $285^\circ$C.

The absence or existence of a delay in creep processes at elevated temperatures in spite of the presence of nonequilibrium stresses which arise under conditions of active deformation should probably be explained by dynamic strain aging of metal which develops with a halt in the deformation process.

This feature of creep process development in view of the effect of the form of stressed state may be followed by comparing irreversible strains accumulated in the first creep stage $\varepsilon_{1\text{f}}$ for the same time intervals in relation to the amount of prior strain $\varepsilon_{i0}$ (Fig. 3).

As can be seen, in the region of uniform strains the dependence in question is invariant to the form of stressed state as in the case of other materials [3]. With certain amounts of strain clear scatter of curves is observed which is explained by the effect of the form of stressed state on the amount of accumulated irreversible strain with which the deformation process loses stability. In the region of quasistatic failure the instant of a changeover from the first creep stage to the second (steady-state), as noted in [6], is caused by equilibrium of the material strain hardening processes and a reduction in the supporting capacity of the test object as a result of a change in the effective specimen cross section and the increase in true stresses connected with it. As a result of loss of stability for the deformation process there is a change-over to the third creep stage.

Under conditions of nonuniform biaxial tension ($K = 0.5$ and 2) for a tubular specimen these processes occur sooner which explains the markedly smaller equilibrium irreversible strains at failure.