The case when only one of the cylinders is perturbed is obtained if in the solution we always put λ_1 or λ_2 equal to zero.

By analyzing conditions (3.11) and (3.12) we see that the first stagnant zone is formed at those peaks of the depressions of the inner cylinder for which $\cos[(m_2/m_1)\pi(2N+1)+\varphi_0)]$ takes its greatest value, and for the outer cylinder, conversely, when $\cos[(m_1/m_2)(2\pi n-\varphi_0)]$ takes its least value.

Figure 1 shows the case then $m_1=4$, $m_2=8$, and $\varphi_0=0$. On the surface of the inner cylinder the stagnant zones are formed in all depressions simultaneously, since $\cos 2\pi(2n+1)=1$ for any n. On the outer cylinder stagnant zones are formed first at points 1, 3, 5, and 7, since at these points $\cos n\pi=-1$, and criterion (3.12) is satisfied for the least values of δ_*.

If m_1 and m_2 do not have a common divider, a stagnant zone is first formed at one point. If $m_1=m_2$, stagnant zones are formed simultaneously at all peaks of the perturbations of the inner or outer cylinder. If for assigned parameters it turns out that $\delta_{*1}<\delta_{*2}$, stagnant zones will first be formed on the inner cylinder, and if $\delta_{*1}>\delta_{*2}$ stagnant zones will first be formed on the outer cylinder. If $\delta_{*1}=\delta_{*2}$, stagnant zones will be formed on the inner and outer cylinders simultaneously. Eliminating δ from (3.11) and (3.12) we obtain a relation between the parameters for the simultaneous formation of stagnant zones on the rigid boundaries of both cylinders.

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RELATIONSHIPS BETWEEN THE CREEP STRAIN INCREMENTS AND THE STRESSES FOR NONSTATIONARY LOADING MODES

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It is known that the similarity of deviators of any tensors is a necessary and sufficient condition for a quasilinear isotropic relationship between them [1]. Experimental investigations performed in both domestic and foreign laboratories on the creep in isotropic materials in stationary loading modes (under simple loading conditions for plasticity) confirmed sufficiently well the similarity hypothesis between the deviators of the stress tensor and the strain increment tensor [2]. This justifies extensive propagation of the theories of plasticity and creep which are based on a quasilinear relationship between these tensors. The similarity between the deviators of the above-mentioned tensors is spoiled for nonstationary loading modes and its absence is apparently associated with the nonlinear nature of the relation. The purpose of the experimental investigation performed is to set up the regularity of the deviation of the ratio between the creep strain increments from the similarity condition and the stress deviator for a step change in the stress state with different combinations of the axial tension σ and shear τ.

The experiments were performed at room temperature on tubular specimens (17- and 15-mm outer and inner diameters, respectively, and 50-mm length of the working section). The initial blanks for the specimens were cut from 20-mm-thick slabs of one of the titanium alloys. After fabrication, the specimens were not subjected to any heat treatment. Some data on the elastoplastic properties and the creep properties of this material are presented in [3]. Despite a certain anisotropy in the creep properties of this material, the

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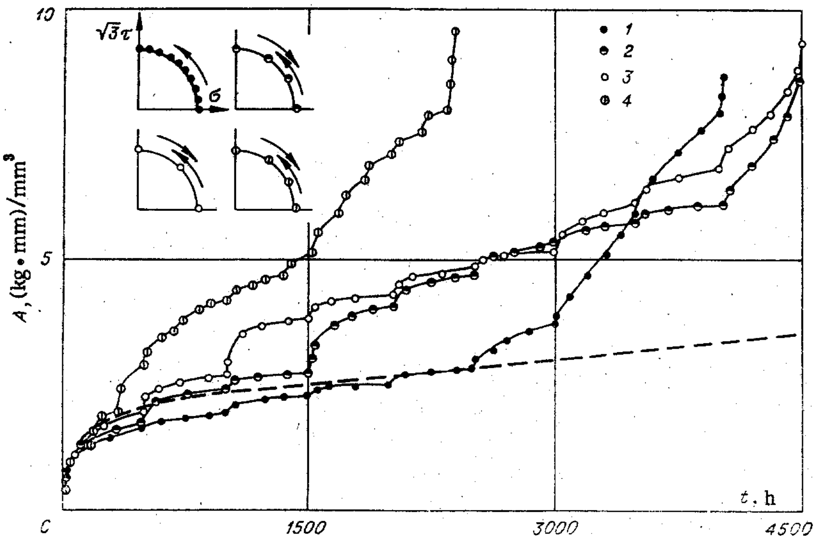

Fig. 1

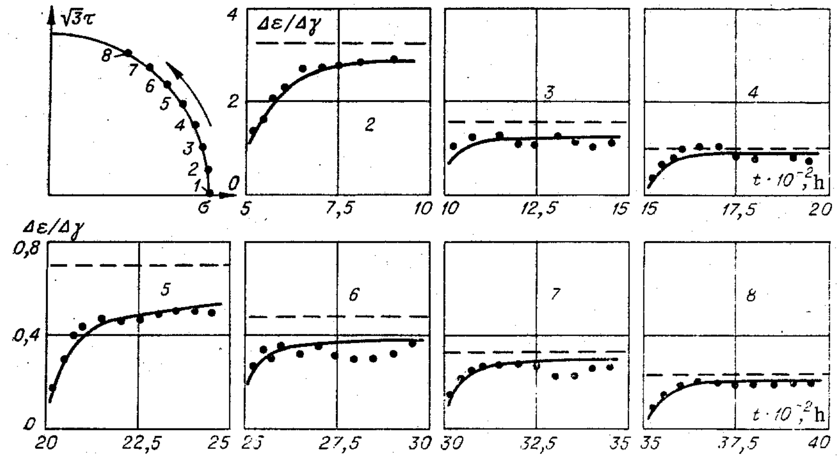

Fig. 2

ratio $\Delta\varepsilon/\Delta\gamma$ was close to the appropriate values of $\sigma/3\tau$ for all stationary loading mode combinations of σ, τ and retained its magnitude up to rupture. Deviations observed in the equality of these ratios with respect to both exaggeration and reduction indicated that similarity of the strain increment and stress deviators was sufficiently satisfactory in the stationary loading mode.

The creep diagrams $A = A(t)$, where $A = \int_0^t \sigma d\varepsilon + \tau d\gamma$, with the stress itensity $\sigma_i = 65$ kgf/mm^2 are represented in Fig. 1. For comparison, the dashed line demonstrates the portion of the diagram for stationary loading modes of the same intensity. Shown schematically in the upper left-hand corner is the sequence of overloads along the level $\sigma_i = \sqrt{\sigma^2 + 3\tau^2} = 65$ kgf/mm^2. The results in diagram 1 refer to the experiment conditions in which the vector mapping the state of stress is rotated in the σ, $\sqrt{3}\tau$ plane through an angle $\Delta\alpha = \pi/20$ from pure tension to pure torsion in $\Delta t = 504$ h (the specimen ruptured in the ninth cycle with a duration of $t_* = 4030$ h). The data of diagram 2 refer to the experiment in which the vector of the stress state was rotated an angle $\Delta\alpha = \pi/6$ from pure tension to pure torsion and back in $\Delta t = 504$ h (the specimen ruptured in the tenth cycle with a duration of $t_* = 4500$ h). The data in diagram 3 were obtained under conditions analogous to experiment 2 but with the angle of rotation of the stress vector $\Delta\alpha = \pi/4$ (the specimen ruptures in the tenth cycle with a $t_* = 4510$ h duration). The data in diagram 4 refer to an experiment with a loading scheme analogous to experiment 2 but with the overload frequency $\Delta t = 168$ h (the specimen ruptured in the fifteenth cycle with a duration of $t_* = 2420$ h).

It is seen from Fig. 1 that up to rupture the magnitude of the energy dissipated during creep $A_* = A(t_*)$ is practically the same in all the experiments, is independent of the loading history, and close to the values of

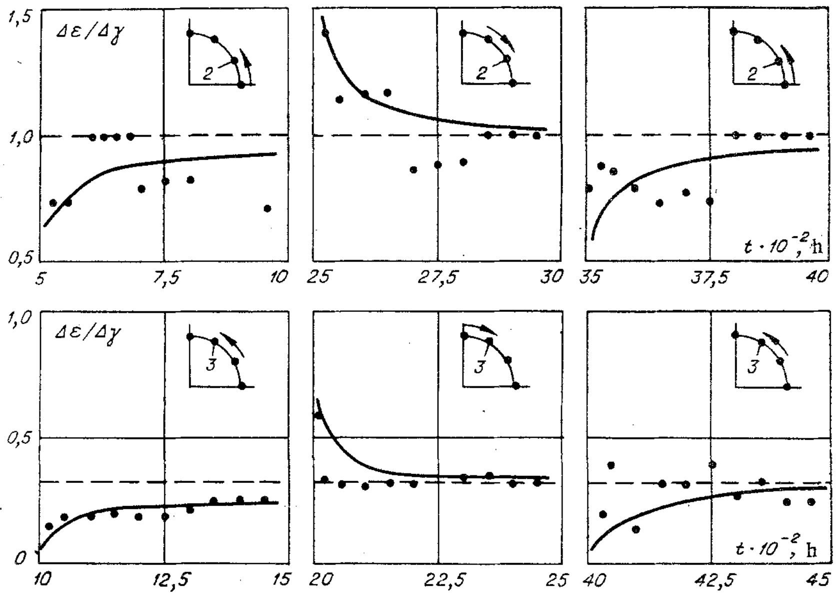

Fig. 3

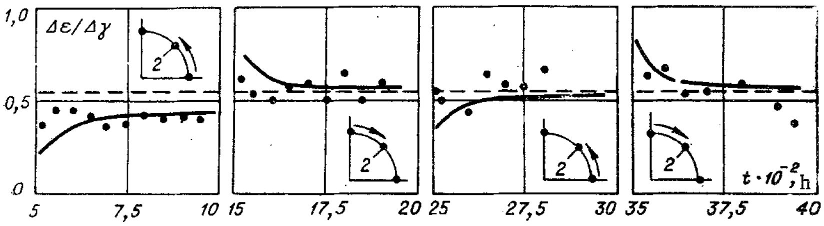

Fig. 4

A_* in the experiments with a stationary loading mode. A certain intensification in the creep process is observed at the time of the overloading, which will last on the order of 200 h, after which the creep process will proceed at same intensity as in the stationary loading experiments.

Diagrams of the ratios $\Delta\varepsilon/\Delta\gamma$ as a function of time from the time of the overload in experiment 1 are represented in Fig. 2. The points here denote values of $\Delta\varepsilon/\Delta\gamma$, the solid lines indicate the general nature of the change in these ratios with time, while the dashes indicate the magnitude of the ratio $\sigma/3\tau$ in the corresponding loading cycle (the numbers refer to points of the stress state in the same loading cycle). As should have been expected, the vector of the creep strain increment deviates substantially from the normal direction to the contour σ_i =const towards rotation of the vector mapping the stress state at the time of the overload even in such an experiment with a weak unilateral change in the form of the stress state. As time elapses the ratio $\Delta\varepsilon/\Delta\gamma$ tends to some constant value close to the appropriate value of $\sigma/3\tau$ but this quantity was not reached in any of the cycles.

Analogous diagrams are represented in Fig. 3 for experiment 2. Here, as in the preceding case of a unilateral change in the stress state, the ratio $\Delta\varepsilon/\Delta\gamma$ does not reach the appropriate value of $\sigma/3\tau$ in the first diagrams along the vertical. For subsequent overloads at the same point of the stress state, the ratio $\Delta\varepsilon/\Delta\gamma$ does reach the appropriate value of $\sigma/3\tau$. The tendency of the quantity $\Delta\varepsilon/\Delta\gamma$ to the appropriate value of $\sigma/3\tau$ apparently proceeds considerably more rapidly for cyclic changes in the stress with a multiple return to the same point of the stress state σ and τ.

Analogous diagrams of the respective experiments 3 and 4 are represented in Figs. 4 and 5. The diagrams of these experiments confirm the previous deduction: similarity between the deviators of the creep strain increment tensors and the stress tensors is restored sufficiently rapidly under multiple cyclical duplication of the same stress state.

It is seen from an analysis of Figs. 1-5 that the duration of intensification of the creep process after an overload (see Fig. 1), and the duration of an abrupt deviation of the values of $\Delta\varepsilon/\Delta\gamma$ from the similarity

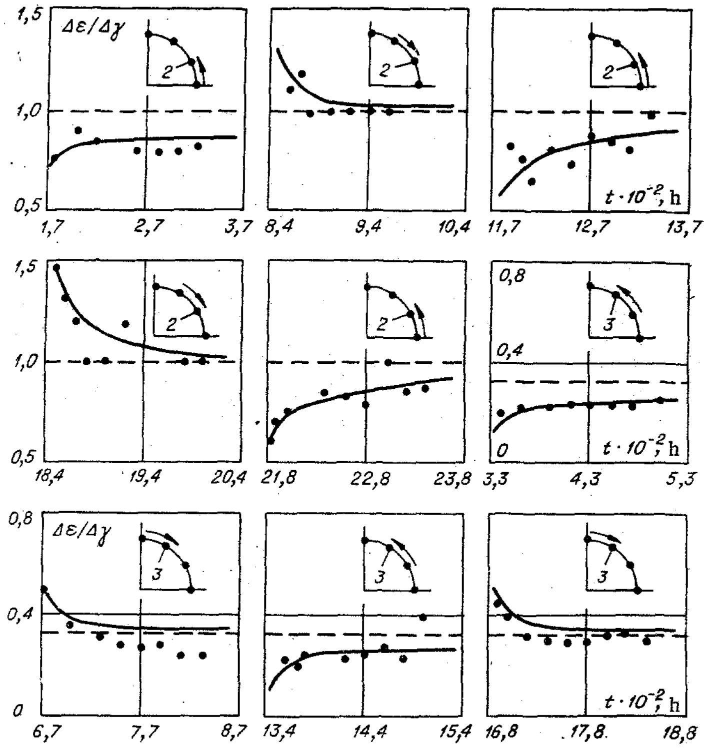

Fig. 5

condition (see Figs. 2-5) practically agree. It hence follows that for time intervals directly after the overloads, and for the whole duration of the process during a continuous change in the stress state, the conditions of a quasilinear isotropic relationship between the creep strain increment and the stress tensors are not satisfied and nonlinear tensor relations must be used to describe nonstationary processes.

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