STRENGTH CHARACTERISTICS OF TITANIUM ALLOYS

A. F. Nikitenko, O. V. Sosnin,
N. G. Torshenov, and I. K. Shokalo

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The experimental results of this paper have been obtained on the same titanium alloy as in [1], but over a wider range of stresses and with process durations of up to $2 \cdot 10^4$ h. The program of the experiments consists of three series: 1) the determination of the elastoplastic properties of the material with different combinations of tensile stress and torque; 2) determination of the creep and long-term strength properties of the material with single-axis loading; and 3) determination of the creep and long-term strength properties of the material with different combinations of stress and torque. Just as in [1], the direction of the largest dimension of the sheet with a thickness of 20 mm, from which the blanks for the samples were cut out, in the future will be called arbitrarily the longitudinal direction, and the direction perpendicular to it in the plane of the sheet will be called the transverse direction. The entire experimental program was carried out on tubular samples with external and internal diameters of 17 and 15 mm, respectively, and with a working part length of 50 mm. After preparation, the samples did not undergo any thermal processing.

Figure 1 shows the results of the experiments to determine the elastoplastic properties of the material. The open circles, black triangles, and crosses in the diagram are the results of experiments on longitudinal samples with pure stress, pure torsion, and with the ratio $\sqrt{3}\tau/\sigma = 0.577$, respectively. The open triangles and black dots are data from tests of transverse samples with pure torsion and with a ratio of $\sqrt{3}\tau/\sigma = 0.577$, respectively. Here $\sigma_i = \sqrt{\sigma^2 + 3\tau^2}$, $\varepsilon_i = \sqrt{3\gamma^2/4(1+\mu)^2 + \varepsilon^2}$, and μ is Poisson's coefficient (found from single-axis experiments by tension and compression) and is taken equal to 0.37. In the experiments with different combinations of σ and τ, during gradual loading the ratio τ/σ was maintained constant, i.e., "simple loading" was achieved. Experiments were carried out also under "nonsimple loading" conditions within the limits of the elastic region, and no deviations of the experimental points from those shown in the diagram were observed. The results of Fig. 1 and and also similar data for single-axis processes, obtained in [1], show that within the meaning of elastoplastic properties, the material can be assumed to be completely isotropic with identical properties in tension and compression.

The pattern of the strength properties of the material in the case of a long-term process is completely different. Figure 2 shows the creep diagrams $\varepsilon = \varepsilon(t)$, obtained by extension of longitudinally directed samples (open circles) and transversely directed samples (black dots). The numbers on the diagram denote the magnitude of the initial stress in kg/mm^2 and the crosses denote creep data in the case of compression of a longitudinally directed sample. The latter experiment was undertaken with a gradual increase of stress from $\sigma = 67$ kg/mm^2 at the first stage up to $\sigma = 7.15$ kg/mm^2 at the last stage.

All experiments with tension were carried out with a constant external load P_0. Hence, it follows from the condition of incompressibility $F_0 l_0 = Fl$ that the stress in the sample increases monotonically according to the relation $\sigma = \sigma_0 l/l_0 = \sigma_0(1 - |\varepsilon|)$. In the compression experiments, if the load remains constant, the stress will decrease according to the relation $\sigma = \sigma_0\,(1 - |\varepsilon|)$. In order to set up the processes under identical conditions, the load in the compression experiments was corrected according to the relation $P = P_0(1 + |\varepsilon|)/(1 - |\varepsilon|)$, which, in consequence of incompressibility, led to an increase of stress in the sample in the same relationship as in the case of tension.

The diagrams presented in Fig. 2 show clearly that, within the meaning of creep processes, the material is strongly anisotropic and possesses different properties in tension and

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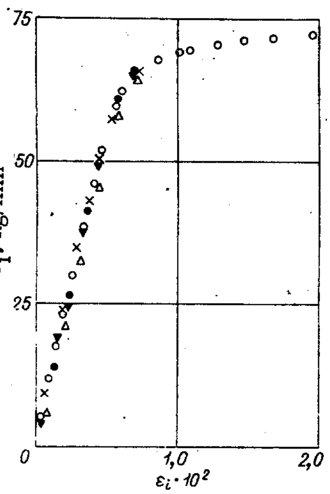

Fig. 1

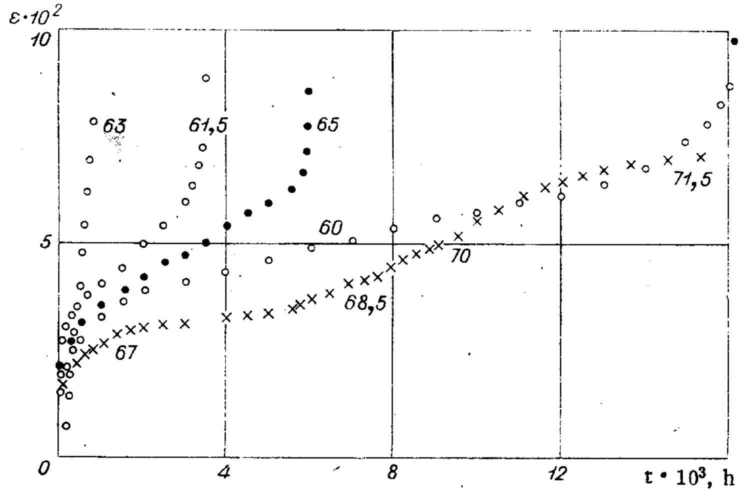

Fig. 2

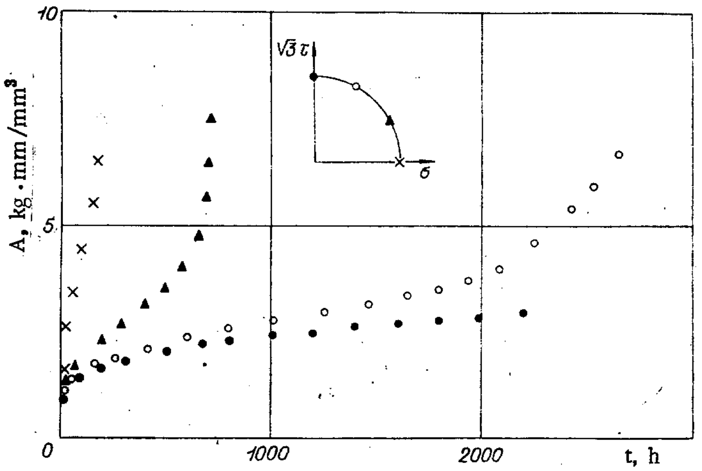

Fig. 3

compression. The duration before failure in the case of stretching of longitudinal samples is less by a factor of 30 than the duration before failure of transverse samples stretched with the same force, and the difference in the durations before failure in the case of tension and compression reaches several orders of magnitude.

This conclusion is confirmed by the experiments carried out with different combinations of stress and torsion on tubular samples cut out from the longitudinal direction. Figure 3 shows the results of experiments in the form of the diagram A = A(t), where A(t) is the magnitude of the specific energy dissipated during creep. The experiments were carried out at one and the same magnitude of the stress intensity $\sqrt{\sigma^2 + 3\tau^2} = 65$ kg/mm²; the signs on the diagrams correspond to the signs of the scheme shown in Fig. 3, top center. In order to make it possible to compare the diagrams A = A(t), corresponding to different combinations of σ and τ, with the diagram of pure stress, just as in the experiments with compression, the initial axial load P_0 and the torque M_0 were corrected by the relations

$$P = P_0(1 + \varepsilon')/(1 + \varepsilon),\ M = M_0(1 + \varepsilon')/(1 + \varepsilon).$$

where ε is the axial deformation at the running time in the experiment carried out; $\varepsilon' = A(t)/\sigma_i$ is the axial deformation which would correspond to the current level of dissipated energy A = A(t) in the experiment with tension and with the same stress intensity.

It can be seen from Fig. 3 that the duration of the creep processes in the experiments, in which the stressed state is close to a pure torque, increases sharply. It is known from [2] that for isotropic materials the creep processes for σ_i = const and for different combinations of the stress components are almost identical.

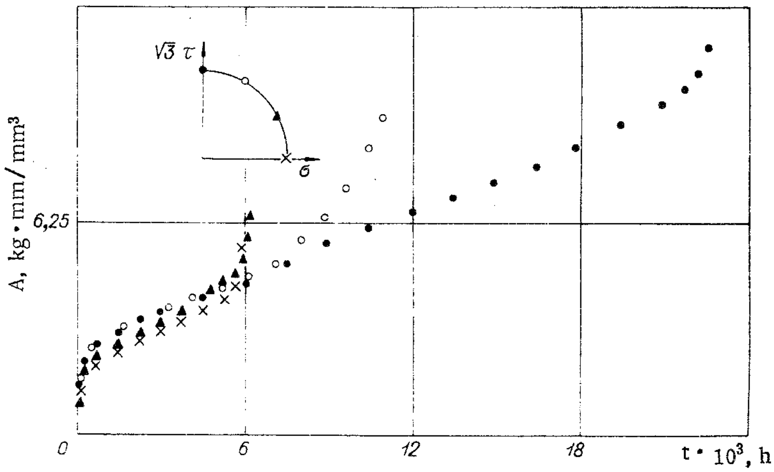

Fig. 4

TABLE 1

Time, h	$\varepsilon\cdot10^2$	$\gamma\cdot10^2$	ε/γ	Time, h	$\varepsilon\cdot10^2$	$\gamma\cdot10^2$	ε/γ
σ = 32,5 kg/mm² τ = 32,5 kg/mm² $\sigma/3\tau$=0,333				σ = 56,4 kg/mm² τ = 18,8 kg/mm² $\sigma/3\tau$=1			
311	1,409	4,372	0,322	48	2,255	2,151	1,048
503	1,701	5,242	0,324	128	2,841	2,666	1,065
1008	2,042	6,421	0,318	192	3,195	3,027	1,055
1511	2,380	7,519	0,316	288	3,691	3,558	1,037
2015	2,902	9,029	0,321	376	4,066	3,925	1,036
2519	3,242	10,236	0,317	472	4,571	4,434	1,031
2553	4,422	13,800	0,320	575	5,358	5,214	1,028
2623	4,712	14,691	0,321	672	7,144	7,111	1,000
2647	4,854	15,187	0,320	691	8,819	8,981	0,982

TABLE 2

Time, h	$\varepsilon\cdot10^2$	$\gamma\cdot10^2$	ε/γ	Time, h	$\varepsilon\cdot10^2$	$\gamma\cdot10^2$	ε/γ
σ = 32,5 kg/mm² τ = 32,5 kg/mm² $\sigma/3\tau$=0,333				9575	4,856	17,159	0,283
				10007	5,447	18,689	0,291
500	0,842	3,273	0,257	10513	5,816	19,974	0,291
1007	1,010	3,960	0,255	10967	6,371	22,282	0,286
1511	1,066	4,191	0,254	σ = 56,4 kg/mm² τ = 18,8 kg/mm² $\sigma/3\tau$=1			
2015	1,291	4,827	0,267				
2519	1,512	5,640	0,268				
3023	1,707	6,361	0,268	504	2,833	3,070	0,924
3527	1,803	6,709	0,269	1008	3,350	3,644	0,919
4031	1,928	7,199	0,268	1512	3,546	3,859	0,919
4535	2,094	7,834	0,267	2016	3,717	4,070	0,913
5039	2,195	8,222	0,267	2520	4,000	4,375	0,914
5543	2,287	8,595	0,266	3024	4,389	4,814	0,912
6047	2,516	9,258	0,272	3504	4,655	5,097	0,913
6551	2,828	10,385	0,272	4008	5,082	5,567	0,913
7055	3,106	11,230	0,276	4512	5,310	5,851	0,907
7559	3,391	12,215	0,278	5016	5,705	6,268	0,910
8015	3,627	13,070	0,277	5520	6,048	6,610	0,915
8567	4,156	14,817	0,280	6024	6,968	7,595	0,917
9071	4,399	15,671	0,281	6122	7,493	8,196	0,914
				6192	8,190	9,001	0,910

Despite the sharply expressed anisotropy of the creep properties, the hypothesis of similarity between the deviators of the stresses and the increments of the creep deformations $\Delta\varepsilon/\Delta\gamma = \sigma/3\tau$ is fulfilled quite satisfactorily right to failure of the material. The corresponding data for longitudinal samples are given in Table 1, whence it follows that the similarity between the stress and deformation deviators (or their rates) is a completely unsatisfactory criterion of isotropicity of the medium.

The results are given in Fig. 4 of experiments on the extension and torsion of tubular samples, cut out from the transverse direction. In all the experiments given here, the intensity of the stresses is the same as in the previous series (σ_i = 65 kg/mm²), and the signs on the diagrams correspond to the signs of the sketch. Table 2 shows the magnitudes of the deformations and their ratios for certain experiments with different combinations of extension and torsion stresses. If the third stage of the creep process is not taken into account, then from Fig. 4 and Table 2 a completely erroneous conclusion can be drawn about the isotropy of the creep properties of the material being considered. Obviously, with a change of the stressed state from the purely tensile to the purely torsion state, on the one hand, the softening effect of the creep properties for the longitudinal direction starts to take effect, and, on the other hand, the hardening effect of the compression creep properties starts to take effect. As the experiments on materials with different properties on tension and compression show, the difference in properties is expressed most strongly in the third stage, which is illustrated graphically in Fig. 4.

It follows from the results presented in Fig. 4 that not only the similarity between the deviators of the stress tensors and the rates of deformation, but also the equivalence of the creep processes for the stressed state with one and the same intensity in the first two stages, is not a sufficient indication of the isotropicity of the medium.

The results recounted above show clearly the complexity of the strength properties of titanium alloys and the impossibility of applying models of an isotropic body to them. In order to describe the processes in media, it will be necessary to devise a theory into account its actual properties. Some of the possible approaches in the construction of such theories are considered in [3-5].

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