JOURNAL OF MATERIALS SCIENCE 16 (1981) 2501–2506

The influence of texture on superplasticity of the titanium alloy VT 6

O. A. KAIBYSHEV, I. V. KAZACHKOV, R. M. GALEEV
Ufa Aviation Institute, ul. K. Marksa 12, Ufa 450025, USSR

This paper describes a specific influence of crystallographic texture on tensile properties of the titanium alloy VT6 under superplastic flow conditions. The texture effect has been examined on alloy states with identical microstructures but with different preferred grain orientations. Tests over wide temperature and strain-rate intervals have shown that the formation of a strong texture as a result of pretreatment of a titanium alloy leads to a decrease in flow stress, an increase in plasticity and a shift of the optimum strain-rate region to higher rates. Data on the effect of texture on the anisotropy of properties of the VT6 alloy are also presented. The present results suggest that the influence of preferred orientation on the characteristics of superplastic flow is a general phenomenon for fine-grained superplastic materials.

1. Introduction

Texture is one of the most important structural parameters determining properties of metals and alloys [1, 2]. In the case of superplasticity a specific influence of preferred orientation on tensile properties of the Zn–22 wt% Al alloy has been established [3–6]. It was shown that in contrast to its influence on the deformation of metals under normal conditions, crystallographic texture caused no anisotropy of flow stress in superplasticity but resulted in a considerable decrease in flow stress and an increase of plasticity compared with a textureless alloy. It is therefore of great interest to study similar texture effects on properties of other metals and alloys and to establish whether they are of universal character. However, it must be stressed that it is difficult to obtain a textureless state which allows one to observe a texture effect in its pure form.

It is the purpose of this paper to report on the influence of preferred grain orientation on the superplasticity of a two-phase titanium alloy VT6.

2. Experimental procedures

The VT6 alloy studied was in the form of hot-rolled rods 25 mm in diameter. The composition of the alloys was (wt%): 6.5 Al; 5.1 V; 0.1 Fe; 0.03 Si; 0.02 C; 0.01 N; 0.003 H_2. In order to distinguish between the effect of crystallographic texture and that of the initial microstructure on superplasticity it was necessary to obtain alloy states differing sharply in preferred grain orientations but having identical microstructures. The initial microstructure of the rods was heterogeneous (α-phase regions of lamellar structure present alongside equiaxed particles), thus it was important to obtain alloy states with an equiaxed homogeneous microstructure. Consequently rods were treated in two regimes at 800 to 900° C: a strong crystallographic texture (State I) was obtained by upsetting and rolling, while a weak texture (textureless State II) was attained by upsetting only. Pole figures of these two textures are given in Fig. 1. In both cases the alloy microstructure was equiaxed and fine-grained, an average grain size being 3.5 μm (Fig. 2).

Tensile tests were carried out in air on an Instron Universal Testing Machine on strip specimens with a gauge section 10 mm × 4 mm × 1.5 mm in a temperature range 20 to 950° C and a strain-rate range 8.3×10^{-5} to 8.3×10^{-2} $\sec^{-1}$. Strain-rate ($\dot{\epsilon}$) and strain (ϵ) dependence of flow stress (σ), the curve of elongation (δ) as a function of strain-rate and the temperature dependence of flow stress at a constant strain-rate were plotted from the results of these tests. The values of

0022–2461/81/092501–06$02.60/0

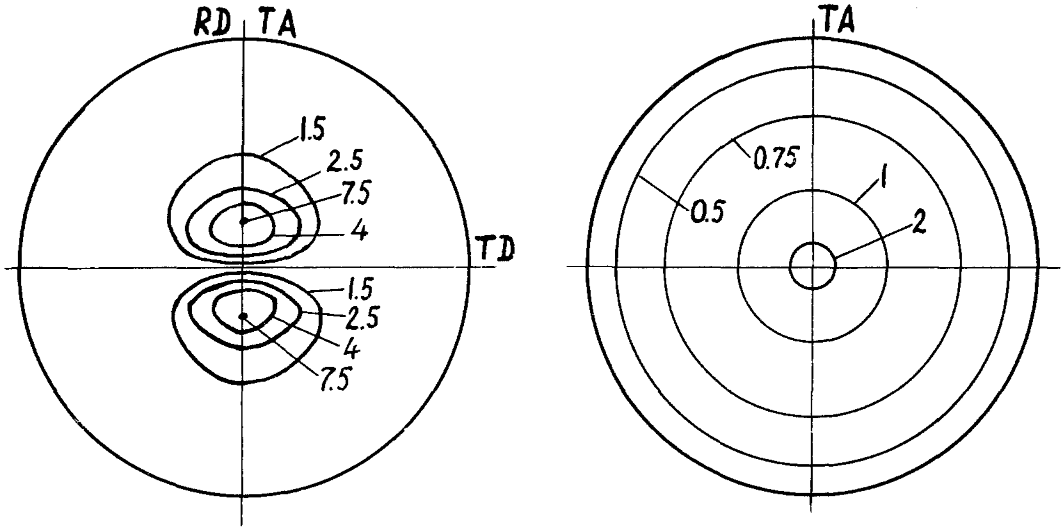

Figure 1 (0002) pole figures for the α-phase of the VT6 alloy: (a) State I. (b) State II. RD = rolling direction, TD = transverse direction, TA = tensile axis.

strain-rate sensitivity (m) were obtained from the slope of log σ–log $\dot{\epsilon}$ curves. The accuracy of the values of σ and δ were 3 and 5%, respectively.

3. Results

Analysis of the tensile properties of the VT6 alloy carried out on specimens cut in the direction coinciding with the axis of the initial rod and the rolling direction at temperatures of superplastic deformation has shown that m, σ and δ dependences are typical of superplastic materials [3, 7, 8]. At the same time properties of the textured and textureless states were observed to differ greatly. Thus, Fig. 3 shows the stress–strain curves at $\dot{\epsilon} = 1.6 \times 10^{-3}$ sec^{-1} at 800 and 850° C. As the testing temperature decreased, the difference in flow stress between States I and II increased. The difference in σ was retained throughout the studied interval of degrees of strain up to 150%.

The flow stress in textured State I is lower for all strain-rate ranges (Fig. 4). Also, for the textureless State II at 800° C the maximum in m is observed at $\dot{\epsilon} = 2.5 \times 10^{-4}$ sec^{-1} and for the textured state m is a maximum at $\dot{\epsilon} = 1.3 \times 10^{-3}$ sec^{-1}, i.e. the optimum strain-rate increases by a factor of 5 with increasing texture (Fig. 4). As the testing temperature increased this difference in optimum strain-rate decreased (Figs 4 and 5).

As shown in Fig. 5, the values of elongation, whose change with strain-rate correlates with the strain-rate dependence of m, are considerably smaller in the textureless state than in the textured one. For the textured state δ is 1100% at $\dot{\epsilon} =$

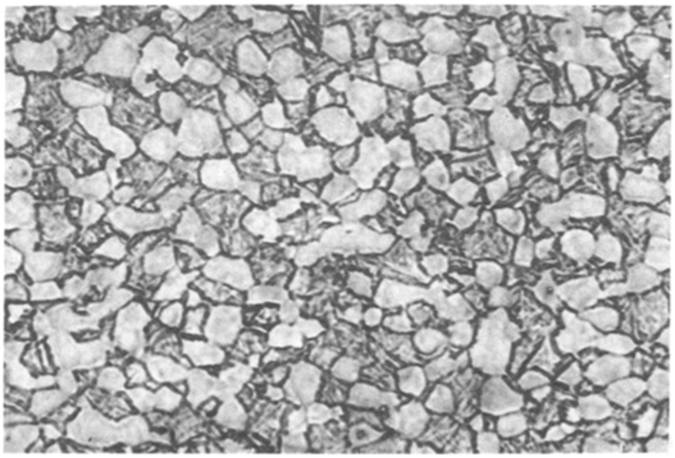

Figure 2 Microstructure of the VT6 alloy after different pretreatment regimes.

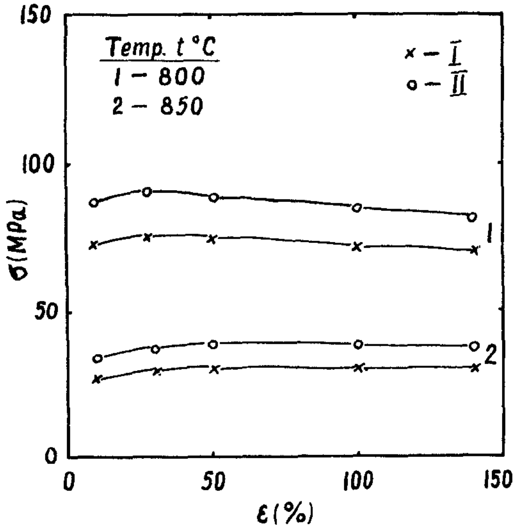

Figure 3 True stress–true strain curves on extension with $\dot{\epsilon} = 1.6 \times 10^{-3}$ sec^{-1} at 800 and 850° C for the two different states of the alloy.

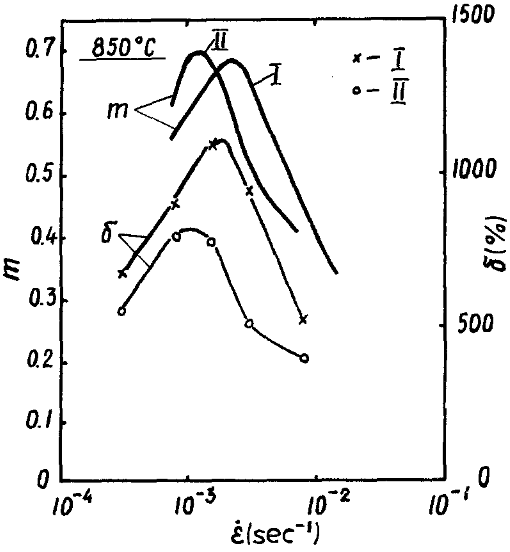

Figure 5 Strain-rate dependence of δ and m measured at 850° C: (I) strong-texture state; (II) textureless state.

1.6×10^{-3} sec^{-1} whereas at the optimum strain-rate in the textureless state δ is only 800 %.

Analysis of the temperature dependence of σ and δ for both states revealed that the above texture effect was present at temperatures below 950° C. However, as mentioned for the exponent m, the differences in σ and δ for the textureless states increased as the temperature decreased. According to the results presented in Fig. 6, at 700° C elongation for the textured state is 3 times that of the textureless one, whereas at 900° C δ of the textured state is only 1.07 times greater.

Thus, the presence of crystallographic texture in the VT6 alloy strongly influences the parameters of superplastic deformation. In a textureless state the alloy shows the greatest values of flow stress and the lowest plasticity compared with the textured state over the temperature and strain-rate intervals investigated.

Data on the effect of texture on the anisotropy of properties of the VT6 alloy are consequently of interest. For such tests, specimens were cut at 0, 45 and 90° to the axis of the initial rod coinciding with the rolling direction. The results on the anisotropy of tensile properties of the alloy at

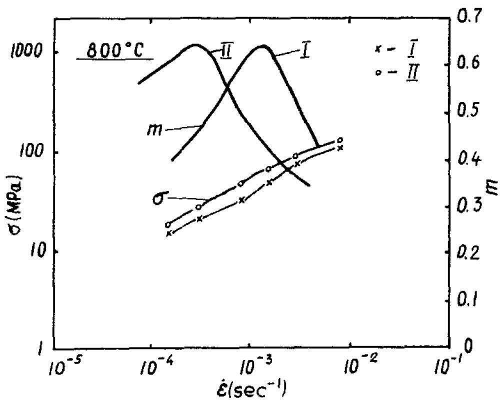

Figure 4 Strain-rate dependence of σ and m measured at 800° C: (I) strong-texture state; (II) textureless state.

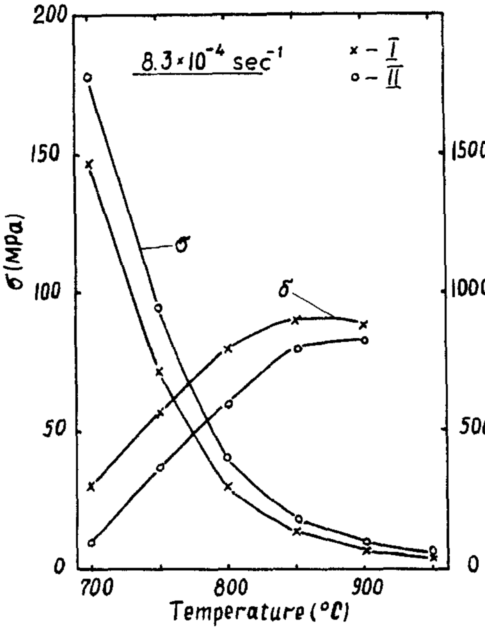

Figure 6 Temperature dependence of σ and δ measured at $\dot{\epsilon} = 8.3 \times 10^{-4}$ sec^{-1}: (I) strong-texture state; (II) textureless state.

TABLE I Anisotropy of tensile properties of the titanium alloy VT6 after different types of pretreatment at a strain-rate of 8.3×10^{-4} sec^{-1}

State	Angle between the rolling and the tensile directions (°)	T (°C)															
		20		300		600		700		800		850		900		950	
		σ(MPa)	δ(%)	σ(MPa)	δ(%)	σ(MPa)	δ(%)	σ(MPa)	δ(%)	σ(MPa)	δ(%)	σ(MPa)	δ(%)	σ(MPa)	δ(%)	σ(MPa)	δ(%)
I	0	1090	29	795	26	374	130	134	290	47	800	14	900	7.3	880	9.0	300
	45	970	25	810	28	376	160	140	380	46	980	12.8	1100	6.8	1000	8.6	310
	90	1000	28	805	24	375	120	125	170	42	650	10.2	700	6.2	680	8.1	280
II	0	1000	22	800	26	410	40	162	100	54	600	17.3	800	8.9	830	9.2	300
	45	980	22	790	26	–	–	163	120	56	620	17.3	800	–	–	–	–
	90	970	21	790	26	–	–	157	140	55	620	17.4	820	–	–	–	–

various testing temperatures are documented in Table I. There is no anisotropy of ultimate tensile strength (σ_b) or of plasticity in the textureless specimens whereas anisotropy of tensile properties is observed for the textured state.

It should be noted that the character of anisotropy of tensile properties during superplastic deformation differs from that during normal deformation. In a superplastic condition the ultimate tensile strength is a minimum in the transverse direction while in the longitudinal one it is somewhat greater than at 45° to the rolling direction. Thus, at 850° C σ_b is 14 MPa in the longitudinal direction and 10.2 MPa in the transverse direction. Elongation is observed to be a maximum at 45° to the rolling direction and a minimum in the transverse direction. As the testing temperature was decreased the relative difference in plasticity of the specimens cut at different angles increased.

This type of anisotropy of σ_b and δ is retained down to 700° C, but with further temperature reductions the anisotropy of δ decreases sharply and at 300 to 600° C anisotropy of σ_b is absent and at 20° C anisotropy of σ_b and δ changes. This change in the type of anisotropy of the ultimate tensile strength and plasticity when the character of crystallographic texture is retained in the temperature interval of deformation from normal to superplastic indicates, therefore, the specific effect of texture on tensile properties of the alloy in a superplastic condition.

4. Discussion

It should be noted that for superplastic Zn–22 wt% Al [4–6] and L59 bronze [9] having a sharp texture, anisotropy of flow stress was unobserved. The absence of anisotropy of flow stress was also established for the Ti–6 wt% Al–4 wt% V alloy with an equiaxed structure and strong texture [10]. As a result, the authors [10] drew a conclusion about the absence of a texture effect on the properties of the superplastic Ti–6 wt% Al–4 wt% V alloy. However, from the available experimental data, anisotropy of tensile properties will hardly characterize the texture effect unambiguously. A comparative study of textured and textureless specimens with similar microstructures should be undertaken to determine the influence of preferred orientation on the properties of alloys. According to the results listed in Table I, the ultimate tensile strength of the alloy in State II is lower than that for the alloy in State I. Such an effect is observed in all three tensile directions, i.e. it is obviously caused by differences in preferred grain orientations for States I and II of the VT6 alloy.

Comparison of the results of the present work and the data obtained on the Zn–22 wt% Al alloy [4–6] has made it possible to conclude that texture formation produces similar changes in the properties of these materials. Both in the Zn–22 wt% Al alloy and the VT6 alloy a strong preferred orientation reduced the flow stress, increased elongation and shifted the optimum strain-rate interval to higher strain rates. For the Zn–22 wt% Al alloy such a texture effect has been obtained for the formation of two different textures. Thus, the experimental data suggests that the influence of preferred orientation on the characteristics of superplastic flow is a general phenomenon for fine-grained superplastic materials.

We now consider possible reasons for such a change in properties of these alloys. Under the conditions of normal deformation of large grained materials the texture effect is connected with preferred orientation of slip and twinning systems relative to the actual stress. However, the role of this factor in superplastic materials changes sharply because of specific mechanisms of the superplastic flow. The role of grain boundaries in deformation processes increases considerably during hot plastic deformation of ultrafine-grained materials. Such processes as dislocation generation, their climb and annihilation, grain boundary sliding, grain boundary diffusion at the given testing parameters and similar microstructure depend mainly on the grain boundary structure which, in its turn, is connected with the misorientation between grains and crystallographic texture. The relation between preferred grain orientation and grain boundary structure has been observed elsewhere [11]. Thus, under the specific conditions of superplastic flow, texture may influence plastic properties of materials as a result of changes in the grain boundary structure.

The results documented in Table I show that the influence of texture on the properties of the VT6 alloy (a decrease in ultimate tensile strength and an increase of plasticity) reveals itself at $T \geqslant 600°$ C. Thus, a specific texture effect on the tensile properties of the alloy is observed at temperatures where hot deformation processes in the grain boundaries contribute to the mechanism of plastic flow. Below 600° C the difference between the two alloy states may be accounted for only by anisotropy of properties, i.e. under the conditions of ordinary deformation a specific texture effect is absent.

It should be noted that the influence of preferred grain orientation on the tensile properties of the alloy is observed in the temperature interval of phase transformation accompanied by microstructural changes. In this alloy a change of phase proportion and composition occurs during heating in the temperature range 800 to 900° C, e.g. the amount of α-phase at 800° C is 75% whereas at 900° C it is only 50%. This fact may be responsible for a weaker influence of crystallographic texture on superplasticity of the alloy at temperatures above 850° C. The decrease in plasticity and small increase of ultimate tensile strength at 950° C may depend also on the oxidation of the alloy during the process of deformation.

5. Conclusions

(1) Crystallographic textures influence the superplastic flow of the titanium alloy VT6.

(2) The formation of a strong texture as a result of pretreatment of a two-phase titanium alloy causes an increase in plasticity, reduction in flow stress, a shift of optimum strain-rate range to higher rates and makes it possible to extend the temperature interval of superplastic deformation to lower temperatures.

References

1. G. WASSERMANN and J. GREWEN, "Texturen Metallischer Werkstoffe", 2 Aufl, (Springer-Verlag, Berlin, 1962).
2. I. P. KUDRYAVTSEV, "Tekstury v Metallakh i Splavakh", (Metallurgizdat, Moskva, 1965).
3. O. A. KAIBYSHEV, "Plastichnost i Sverkhplastichnost Metallov", (Metallurgizdat, Moskva, 1975).
4. O. A. KAIBYSHEV, I. V. KAZACHKOV and S. Ya. SALIKHOV, *I. Vozov, Tzvetnaya Metallurgiya* N2 (1975) 108.
5. O. A. KAIBYSHEV, I. V. KAZACHKOV and S. Ya. SALIKHOV, *I. Vuzov, Tsvetyana Mettallurgiya* N3 (1978) 124.
6. O. A. KAIBYSHEV, I. V. KAZACHKOV and S. Ya. SALIKHOV, *Acta Met.* **26** (1978) 1887.
7. J. W. EDINGTON, K. N. MELTON and C. P. CUTLER, *Progr. Mater. Sci.* **21** (1976) 51.
8. M. V. GRABSKII, "Structurnaya Sverkhplastichnost Metallov", (Metallurgizdat, Moskva, 1975).
9. V. K. PORTNOI, I. I. NOVIKOV, B. N. EFREMOV and V. A. KOZHANOV, *I. Vozov, Tsvetnaya Metallurgiya* N5 (1979) 103.
10. N. E. PATON and C. H. HAMILTON, *Metall. Trans.* **10A** (1979) 241.
11. D. E. FLEET, P. J. WELCH and P. R. HOWELL, *Acta. Met.* **26** (1978) 1479.

Received 2 December 1980 and accepted 2 March 1981.