EFFECT OF STRUCTURAL INSTABILITY ON CREEP OF ZIRCONIUM SUBJECTED TO SEVERE PLASTIC DEFORMATION

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The peculiarities creep and electro-physical characteristics of zirconium subjected to severe plastic deformations by rolling on the different degrees at 300 K was studied. It is shown that in the process of creep of zirconium due to changes in the conditions of deformation the structure, which was created by rolling, becomes unstable. A plastic flow is carried out because of structure rearrangement at joint action of several mechanisms and accompanied by stress relaxation.

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INTRODUCTION

It is known that as a result of severe plastic deformations boundaries are formed, a crystal is divided on a microregions (fragments), disoriented on angles about a few degrees [1]. By increasing the degree of deformation becomes smaller fragments, they are axially elongated and stronger deployed relative to one another.

Fragmentation is the dominant mode of evolution of the defect structure on the stage of developed plastic deformation.

Such a structure is typical for cold rolling.

The boundaries of the fragments are the dense dislocation formation, the structure of which regulated with increasing strain, but the main thing is that in proportion to the increase of deformation the disorientation of angles in a fragmented structure increased, i.e. the high angle boundaries is forming, which increase the kinetic stability of the structure [2-4].

It is known that the nature of the external action determines the resistant type to the structural state in relation to it. Changing the geometry of plastic deformation is accompanied by structural restructuring so as to cause the maximum intensity of the internal stress relaxation in line with the desire to maintain continuity of the crystal [1].

The newly formed structure as a result of alteration also can be fragmented, but steady in relation to the new scheme of the elastic-stress condition and a temperature-rate mode of deformation [1, 2].

In purpose of study the features of the fragmented structures of zirconium, created by severe rolling deformation at 300 K, the creep and electro-physical properties are investigated.

MATERIAL AND EXPERIMENTAL PROCEDURE

The bar of Zr, obtained by electron beam melting, was cut into templates and strained by rolling at 300 K on different degrees, veritable deformation of specimens (ε) was 0.35; 0.7 and 2.5.

Measurements of the electrical resistance R were made using the compensation scheme. Differential termoelectromotive force (S) was determined at a room temperature in relation to a copper; the temperature gradient along specimens was ~ 20 K. Measurement error of R and S does not exceed ± 0.5%.

Creep tests were carried out in the step loading regime at 300 K, the measurement accuracy was $5 \cdot 10^{-5}$ cm. The activation parameters and level of internal stresses were determined using the differential methods described in [5].

RESULTS AND DISCUSSION

After deformation by rolling at different degrees the values of specific electrical resistance (ρ) and termoelectromotive force were determined. The resulting dependences ρ and S on the true strain are shown in Fig. 1.

The character and rate of defect accumulation, according to the changes in electrical properties depend on the strain only in the initial stages of rolling ($\varepsilon < 0.7$).

Electrical resistivity and thermoelectric power are practically independent on the strain with further increase in the degree of rolling

The creep rate is also weakly dependent on the value of deformation by rolling, thus decrease in electrical resistance during creep was observed for all samples, indicating that reducing the level of internal stresses.

In the all investigated temperature range there is a big creep rate for all samples and the dependence of the deformation value from test time is described by a power law ($\varepsilon \sim t^{1/3}$), which may be the result of the simultaneous action of the hardening and recovery [7], i.e. plastic flow is caused by the combined action of several mechanisms.
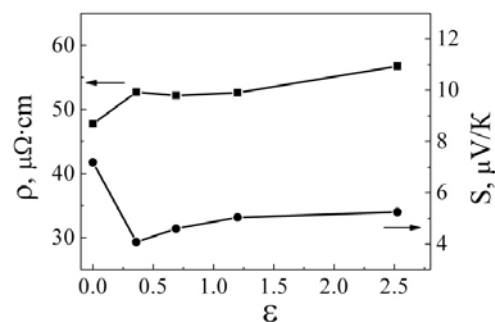

Fig. 1. Dependences of specific electrical resistance (ρ) and termoelectromotive force (S) of zirconium from the degree of true deformation (ε) by rolling at 300 K

The dependence of the creep rate of zirconium, strained by rolling to different degrees, from the applied stress and the corresponding change in the electrical resistivity are shown in Fig. 2.
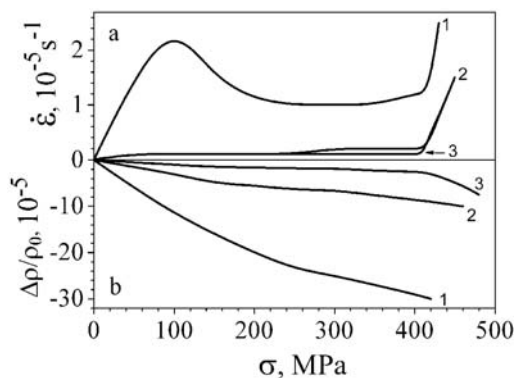

Fig. 2. Dependence of creep rate and specific electrical resistance (ρ) of zirconium, strained by rolling at 300 K, from the working stress (σ) :
1 – ε ≈ 0.35; 2 – ε ≈ 0.7; 3 – ε ≈ 2.5

As can see in Fig. 2, after the first stage of rolling (ε ≈ 0.35) observed high rate of creep at all stresses, even at $\sigma < \sigma_{0.2}$ (curve 1).

Since strain ε ≈ 0.7 and above, the rate of creep and the electrical resistivity are weakly dependent on the value of pre-strain rolling. The decrease in resistivity during creep is observed for all samples, that testifies a decrease in the level of internal stress.

The calculated value of the activation volume is ~10^{21} cm³, indicating the localization of plastic flow [6].

We will consider the possible reasons for the observed effects. According to our structural studies the developed network of dislocation boundaries with a density of free dislocations within them $\rho \approx 9 \cdot 10^{10}$ cm⁻² is observed in the material (Fig. 3), as a result of rolling deformation at 300 K on ε ≈ 0.35.

Such structures are kinetically unstable during creep and begin to rebuild even at stresses lower than the yield stress, which is accompanied by a strong decrease in the level of internal stress (see Fig. 2, curve 1).

This is a consequence of another scheme loading the material with a low deformation rate. As a result, as shown in Fig. 3,b, a less strained cellular structure between powerful high-angular boundaries is formed.

It should be noted that the signs of the collective organization of dislocations: tangles, clusters, ragged dislocation boundary (see Fig. 3) appear already at the amount of deformation by rolling 0.35.

It seems that the plastic flow during creep first carried out by sliding the free intra-bloc dislocations and output them to the interface.

Next, with the strain raise, the contribution of the relaxation mechanisms increases: dislocation creep at grain boundaries, annihilation of opposite dislocations and absorption the dislocation of boundaries. Thus in boundaries also there can be a redistribution of dislocations, accompanied by some ordering. All these processes lead to micro localization of deformation and stress relaxation.
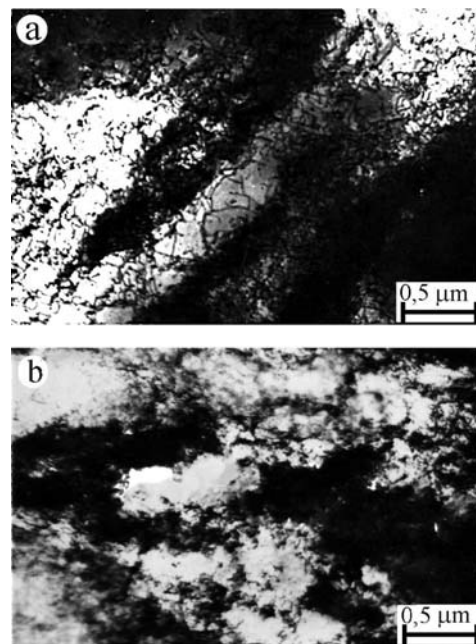

Fig. 3. TEM images of zirconium after rolling at 300 K ε ≈ 0.35 (a) and subsequent creep at 300 K, σ ≈ 0.9 σ_B (b)

Increasing the degree of deformation by rolling weakly influence on dislocation density, but the character of their distribution is changing. When deformation ε ≈ 0.7, the structure become completely fragmented (Fig. 4,a). During creep boundaries of fragments are rearranged so that the structure becomes less stressful and oriented along the axis of tension (see Fig. 4,b).
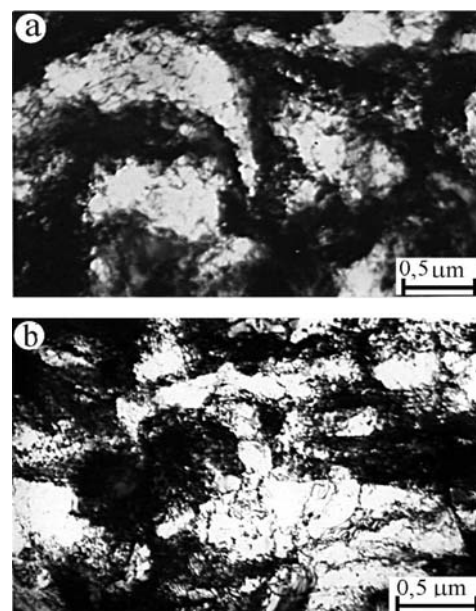

Fig. 4. TEM images of zirconium after rolling at 300 K ε ≈ 0,7 (a) and subsequent creep at 300 K, σ ≈ 0,9 σ_B (b)

With further increase in the degree of deformation by rolling the fragment size decreases and the dislocation structure of the boundaries is ordered, more clearly shows up the elongation of the fragments in the

rolling direction. As a result, at the deformation $\varepsilon \approx 2.5$ a homogeneous fine-structure fragments with high levels of internal stress are formed (Fig. 5) [7].

During the creep deformation, this structure is rearranged and fragmented structure is also formed, but less intense and elongated along the axis of the tensile load (see Fig. 5,b).
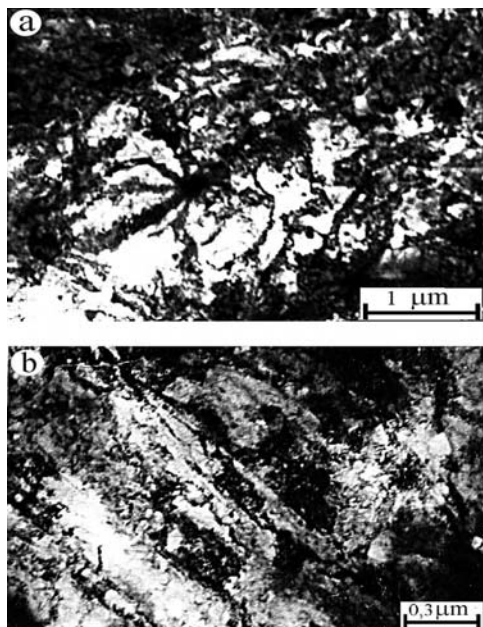

Fig. 5. TEM images of zirconium after rolling at 300 K
$\varepsilon \approx 2.5$ (a) and subsequent creep at 300 K (b)
and $\sigma \approx 0.9\,\sigma_B$

Thus, the plastic deformation of the rolled zirconium is due to the reorganization of the defect structure and is accompanied by stress relaxation. This process includes the destruction of the initial structural configuration, created as a result of deformation by rolling, and the formation of a new structure, which also is fragmented, but less tense and steadier to subsequent deformation.

At the first, being in the other mode of stress- and rate deformation, being unable to change during plastic deformation, the initial boundaries are destroyed, trying to adjust the orientation of micro volumes to the direction of tension.

After that, developing a uniformly oriented crystal, plastic deformation creates new boundaries of disorientation, but already steady in relation to new geometry and rate of deformation influence.

The fragmented structure remains steady, despite the radical structural alterations, as the boundaries of fragments are not the only areas where dislocations are going, trying to reduce the elastic energy of the crystal, or barriers to the development of intra-fragments deformation (they would inevitably destroyed), but are independent participants in the process of plastic deformation.

The condition of safeguarding continuity of the crystal requires the equality of the stress relaxation rate and their rate of growth. At a plastically deformed sample the energy dissipation rate connected with the motion of dislocations. As far as continuation of deformation their motion is held up due to the presence of defects, such as fragments boundaries, and thus for continuation of deformation it is necessary to connect an additional mode of plastic deformation [7-10]. And such mode that would enhance the absorption of the energy supplied to the sample without causing a strong forming. The rotary mode of plasticity satisfies these conditions.

It is necessary to note that the appearance of the fragmented material structure and rotary mode of plasticity correspond to representations Prigozhin-Glansdorff on formation of dissipative structures in materials which experiencing strong external influences [2, 3], i.e. it is possible to see this as a purely synergistic problem.

CONCLUSIONS

Plastic flow of zirconium subjected to severe plastic deformation by rolling under conditions of creep occurs due to the rearranging initial defect structure and is accompanied by stress relaxation.

Deformation is due to the combined action of several mechanisms. At loading near the yield stress the main contribution to creep deformation makes the mechanism of dislocation slip in the volume of fragments.

At loading above the yield stress the main contribution to the deformation and stress relaxation are making recovery processes: the dislocation creep at the boundaries of fragments, dislocation annihilation, etc. Here boundaries of fragment are independent structural elements of deformation. The redistribution of dislocations can occur in the boundaries and is accompanied by some ordering and slip along the boundaries of the fragments.

Continued deformation and the need to develop accommodative processes caused the appearance of rotation plasticity modes in the final stages of deformation at stresses near the ultimate strength.

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ВЛИЯНИЕ СТРУКТУРНОЙ НЕСТАБИЛЬНОСТИ НА ПОЛЗУЧЕСТЬ ЦИРКОНИЯ, ПОДВЕРГНУТОГО ИНТЕНСИВНОЙ ПЛАСТИЧЕСКОЙ ДЕФОРМАЦИИ

Е.В. Карасева, А.В. Мац, В.И. Соколенко, В.А. Фролов

Изучены особенности ползучести и электрофизические характеристики циркония, подвергнутого интенсивным пластическим деформациям прокаткой при 300 K разной степени. Показано, что вследствие изменения условий деформирования в процессе ползучести циркония возникает нестабильность структурного состояния, созданного прокаткой. В результате пластичное течение осуществляется за счет перестройки дефектной структуры и сопровождается релаксацией напряжений. Пластическая деформация сильно деформированного циркония обусловлена общим действием нескольких механизмов.

ВПЛИВ СТРУКТУРНОЇ НЕСТАБІЛЬНОСТІ НА ПОВЗУЧІСТЬ ЦИРКОНІЮ, ПІДДАНОГО ІНТЕНСИВНІЙ ПЛАСТИЧНІЙ ДЕФОРМАЦІЇ

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Вивчено особливості повзучості та електрофізичні характеристики цирконію, підданого інтенсивним пластичним деформаціям прокаткою при 300 K різної ступені. Показано, що внаслідок зміни умов деформування в процесі повзучості цирконію виникає нестабільність структурного стану, створеного прокаткою. В результаті пластична течія здійснюється за рахунок перебудови дефектної структури і супроводжується релаксацією напруг. Пластична деформація сильно деформованого цирконію обумовлена спільною дією декількох механізмів.