INFLUENCE OF THE TEXTURE OF PRISMATIC PLANES ON THE ANISOTROPY
OF DEFORMATION OF IRRADIATED ZIRCONIUM ALLOYS

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The rate at which the dimensions of zirconium alloy members change as a result of deformation under irradiation often determines the service life of these members. For example, the service life of the fuel channels (FC) of RBMK reactors [1] is limited by an increase in the tube diameter until contact is made with the surrounding graphite stacking. In the case of fuel-element cans, crumpling of the cans as a result of an azimuthally anisotropic buildup of strain can be the limiting process [2]. Under reactor conditions the service life is also affected by radiation-induced growth, leading to a substantial change in the length of the members.

In a correct consideration of the deformation behavior of hcp zirconium alloys it is necessary to take into account the anisotropy of changes in the dimensions of the fabricated tube. In the case of fuel channels, as a consequence of radiation-induced creep the diameter of a tube made of an anisotropic material may increase twice as slowly as in a tube of isotropic material [3]. Because of the lower rate of creep in the circumferential direction for the anisotropic material, the time until the fuel-element can crumple can also increase severalfold [2].

When considering the creep strain of an anisotropic material, use is made of so-called anisotropy coefficients, which are defined by analogy with coefficients for describing anisotropic plastic strain [4] and enter into the pertinent deviator expressions for the creep rate. For a tube these coefficients are determined experimentally from the ratios of the strains under different loading conditions (e.g., uniaxial or biaxial loading) [5].

A polycrystalline alloy based on α-Zr can have a texture that is formed during fabrication of the tubes. Usually, for anisotropy calculations the texture is considered for {0002} basal planes or the basis vectors of the crystallites relative to the axis of the tube. Such a texture is characterized by the orientation factors $F_R$, $F_T$, and $F_A$ of the basis vectors relative to the tube axis. These factors essentially are the averaged squared cosines of the angles of the basis vectors to the respective coordinate axes. Usually, the direct polar diagram drawn in the plane perpendicular to the tube radius is employed for such averaging (Fig. 1).

A texture model, permitting the anisotropy coefficients to be calculated on the basis of x-ray measurements of the texture of the tube material, has been proposed and tested under reactor conditions [6]. In this case, however, only the basal texture was considered and it was assumed that the orientation of the rotation of the crystallites relative to the basis vectors is equiprobable, i.e., there is no texture of the prismatic planes.

Nevertheless, a number of experimental facts [7] indicate the existence of a texture of prismatic planes. We know of only one paper [8] about the influence of this texture on the plastic strain, but only the mechanism of dislocation slip along prismatic planes was analyzed. In the light of this it is desirable to consider the influence of the texture of prismatic planes on the deformation of zirconium alloys as applied to the main mechanisms of radiation-induced creep and growth.

In hcp metals the basal and prismatic {1010} planes are energetically advantageous for slip [9]. In this case, for a network of line dislocations as well as for dislocation loops formed under irradiation only Burgers vector of the type $b = \frac{1}{3}<1\overline{1}20>$ are observed. From the axial symmetry of the hcp structure it follows that there are three differently oriented {1010} planes, along which line dislocations move, and three {1120} planes, where dislocation loops are formed.

Fig. 1. Orientation of a crystallite relative to the tube axis. Construction of the basal texture diagram \((x, y, z) \rightarrow [\text{Lin} (\alpha_R, \varphi, \delta)] \rightarrow (R, T, A), \ \sigma_{ij} = \sum R \sum j \text{ln} \sigma_{ij}, i, j = x, y, z, \ \varepsilon_{mn} = \sum R \sum j \text{ln} \varepsilon_{ij}, m, n = R, T, A.\)

We assume that both the density of the line dislocations and the density and average size of the loops are the same in the corresponding, differently oriented planes. In this model crystallite deformation processes in the directions of the vectors \(b_1, b_2, b_3\), turned 60° relative to each other, are equiprobable.

For each concrete deformation mechanism we can calculate the reduced stresses from an external load for a given vector \(b\) and the values found for the strain can be recalculated with allowance for the orientation of the crystallite. For this purpose we use the tensor expressions

\[
\sigma_{ij} = l_{im} l_{jn} \sigma_{mn},
\]

where \(i, j = x, y, z; \ m, n = R, T, A;\)

\[
\varepsilon_{hl} = l_{ih} l_{jl} \varepsilon_{ij},
\]

where \(i, j = x, y, z; \ k, l = R, T, A.\)

In expressions (1) we have used components of the \(||L||\) matrix of coordinate transformations obtained by three rotations through angles of \(\alpha_R, \varphi, \delta\), where the angle \(\delta\) specifies the orientation of the crystallite relative to the \(x\) axis. In the case of a prismatic texture the preferred orientation of the crystallites relative to the external system of coordinates was observed.

For further calculation of the strain of specimens cut from a textured tube, the contributions to the strain from individual oriented grains must be averaged, assuming as usual that these contributions are additive.

In order to distinguish the characteristics of the strain anisotropy, we arbitrarily assume that the structure factors, reflecting the dependence of the strain on the external conditions (stresses, temperature, neutron flux intensity) and on the microstructural characteristics of the material, have a value of 1. Since in the range of the operating stresses of reactor structures the creep mechanisms depend linearly on the stress \([10]\), the following estimates are made for unit stress. We calculate the strain under uniaxial loading of specimens cut in the circumferential and axial directions of the tube. For the assumptions made above these strains are equal to the anisotropy coefficients \(C_{TT}\) and \(C_{AA}\) \([6]\).

The influence of the texture of prismatic planes for different mechanisms of deformation under irradiation is illustrated by the results of calculations (Fig. 2) using the example of