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ON ATHERMIC MECHANISM OF MATERIALS RADIATION EMBRITTLEMENT

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To elucidate the mechanisms of radiation embrittlement of materials the temperature dependence of mechanical properties of irradiated materials has been studied. Beams of high-energy electrons (225 MeV) were used for simulation of the fusion reactor radiation effects on materials. Investigations were performed on nickel and OKh18Ni10Ti stainless steel. The relation between radiation embrittlement value and flow stress components behavior (thermal-σ^* and athermic – σ_μ) is determined. The value of radiation embrittlement increases with increasing of relation -σ_μ/σ^*.

INTRODUCTION.

In temperature dependence of a plasticity characteristics of the irradiated materials three typical zones embrittlement, especially brightly shown in materials with a fcc-lattice are clearly expressed: low-temperature radiation embrittlement (LTRE), relevant to test temperatures up to $0{,}35T_m$; high-temperature radiation embrittlement (HTRE), relevant to test temperatures up to $0{,}5T_m$ and transition zone with a high plasticity between LTRE and HTRE

The objective of the present paper is to analyze radiation embrittlement of reactor materials together with temperature dependence of the strength characteristics and account of two flow stress (σ) components: σ^* – thermal-activated, bound with influence of short-range forces (microlevel); σ_μ – athermic, stipulated by long-range drags of dislocations.

Let us consider the temperature dependence of flow stress of materials. It can be presented [1] as several areas essentially different on mechanisms, checking the process of a plastic strain (fig.1).

In low-temperature thermally – activated area (1) ($T \leq 0{,}15T_m$.) the value of activation volume of a plastic strain makes about b^3, i.e. answers micro scale level of dislocation interactions, or so-called «to dot kinetics» of dislocation processes. An athermic component σ_μ in area (2) is determined, in the main, by fields of long-range elastic internal stresses stipulated by interaction of dislocations in parallel slip planes and (or) in intersected slip planes [1,2]. In area (3) ($T \geq 0{,}45T_m$) thermally-activated component is determined by such diffusive processes, as climb of edge dislocations or formation of jogs on screw dislocations. The transferring to the second athermic plateau ($\sigma(T) \sim G(T)$) in area (4) related with to intensification of the grain boundary processes of a plastic strain.

How are connected the changes of σ_μ and σ^* with temperature dependence of the radiation embrittlement in wide ranges of test temperatures, having, at least, a few areas, represented on fig.1? Up to now the such questions practically were not consider.

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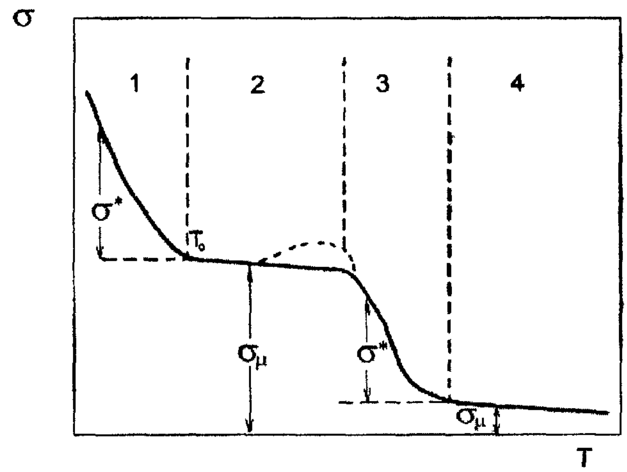

Fig. 1. The generalized plan of temperature dependence of a flow stress in polycrystallic metals (explain in the text).

MATERIALS AND PROCEDURES.

To study the radiation effects on materials the beams of electrons with energy, above threshold of nuclear reactions were used in the present work. Under such irradiation the radiation defects formation (like dislocation loops), also as the nuclear products release is observed like as in reactor [3]. Irradiation was carried out at the accelerator LU-2 GeV. The damage rate was 10^{-7} dpa/s, generation rate of helium by the secondary (γ,α) reaction – $2{,}5 \cdot 10^{-2}$ at. %/dpa. The initial energy of electrons – 225 MeV. The irradiation was carried out in temperature range 170...190°C. The greater part of experiments was carried out on samples irradiated up to doses $1 \cdot 10^{25}$ el./$м^2$, that corresponds to a damage level – 0,1 dpa. Flat samples for mechanical tests with a gauge size 10x3x0.3 mm were tested in vacuum in an interval of temperatures 20...1000°C with strain rate 0,003 1/c.

Materials for examinations were annealed (800°C 1 hour) nickel of electron-beams melting (99,9) and austenitic stainless steel 0Kh18Ni10Ti of the following chemical composition (in wt.%): C – 0.09, Cr – 18, Ni – 10.2, Ti – 0.37, specimens were annealed – 1050°C 30 min.

EXPERIMENTAL.

As it is seen from a fig.2, in the temperatures range – 20...350°C the plasticity of the irradiated nickel is reduced up to minimum value. The decrease of plasticity under irradiation is observed in temperature range, where $\sigma \cong \sigma_\mu$, that is in athermic area corresponding to area (2) on the Fig.1 and secondly, value of an irradiation hardening $\Delta\sigma = \sigma_{irr.} - \sigma_{unirr.}$ in this interval of temperatures also is determined by the value of athermic components change, that is $\Delta\sigma \cong \Delta\sigma_\mu$ and practically does not depend on test temperature.

The transition region between LTRE and HTRE corresponds to second thermally – activated area (3) in a Fig.1, and the maximum of a derivative dσ/dT in this interval of temperatures corresponds to the maximum relative elongation – δ(T) at the irradiated material. In other words, the maximum of the irradiated material plasticity corresponds to the temperature interval dependence of a flow stress where it is determined by behavior of thermally-activated component.

The value of a radiation softening, observed in the HTRE area,(≥700°C), is independent on test temperature and carries athermic character to (see fig.2.).

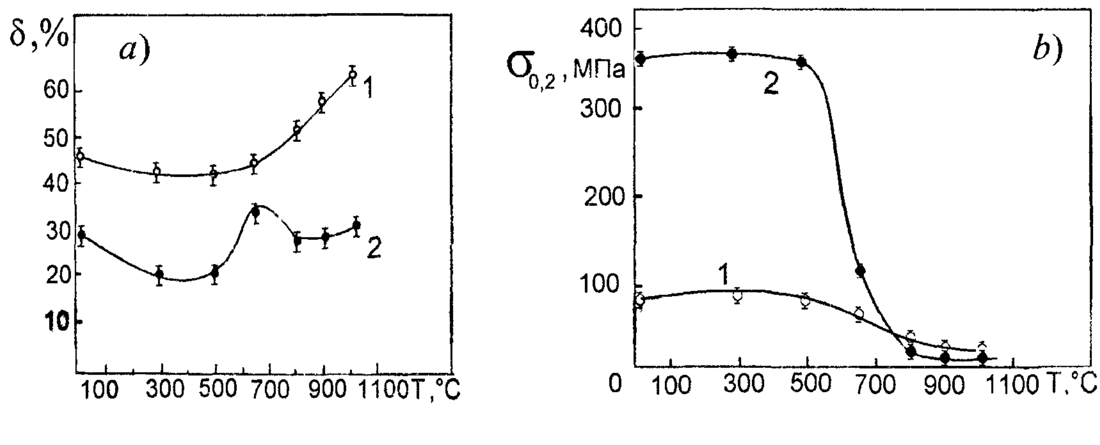

Fig. 2. Temperature dependence of a relative elongation (a) and yield strength (б) of nickel.
1 – unirradiated, 2 – irradiated up to a dose 10^{25} el /м^2.

The results of mechanical tests of irradiated OKh18Ni10Ti SS, have shown, that the intensive decrease of elongation is observed from 20°C up to test temperature 300°C (with 70 up to 18...19%). In unirradiated steel the minimum plasticity is observed in the interval of temperatures 400...600°C, i.e. on an interval of temperatures, where the flow stress of unirradiated steels has the athermic character ($\sigma \cong \sigma_\mu$). At low fluences irradiation (10^{23} el/cm^2) the minimum of plasticity of the irradiated materials "is tied up" to the unirradiated steels minimum, and, thus, is observed in the same interval of temperatures. Effect of deeping and plasticity minimum shift to lower temperature region – 300°C, (like nickel) is observed with fluence increasing up to 10^{25} el/cm^2 This process is determined by forming in the temperatures range – 20...300°C of «new» athermic plateau σ(T), described in [4].

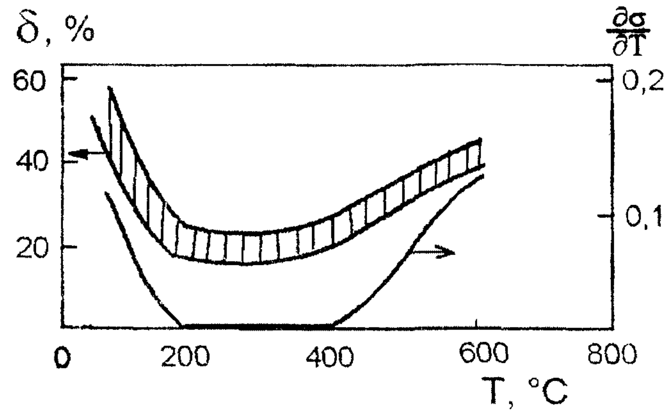

Fig. 3. The temperature dependence of the relative elongation of AISI304 and AISI316 steels irradiated up to fluence $3 \cdot 10^{24}$ neutron/m^2 (dotted area) and $\partial\sigma/\partial T$ that is the slope angle of flow stress temperature dependence in an unirradiated state.

The analysis of the curves σ(T) and δ(T) AISI 304 and AISI 316 SS, irradiated in reactor [5], has shown, that the minimum of plasticity after irradiation also corresponds to an athermic plateau of dependence σ(T), that is zones where dσ/dT ≅ 0 (see fig.3.).

DISCUSSION.

Despite the difference in the nature of LTRE and HTRE these effects have one common mechanism – they are accompanied by the effects of plastic flow localization. In LTRE region: this is the channels of the localized deformation in the grain matrix [4,6]; in HTRE region – this is along the grain boundaries [3].

Results obtained in present paper satisfy the theory of localized dislocation structures development in irradiated deformed material [6]. According to this theory engaging of "dot" dislocation kinetics or plastic deformation microlayer is the necessary requirement for the reduction of localized deformation and as the consequence, reduction of the radiation embrittlement.

CONCLUSIONS.

The relation of the temperature intervals and values of radiation embrittlement with behavior of the flow stress components of materials is analyzed. It is shown that the radiation embrittlement is determined by evolution of long-range modes of plastic strain. Thus the values of LTRE and HTRE increase with the relation σ_μ/σ^* increase – that is long-range athermic and short-range thermally – activated flow stress components. The obtained results correspond to theoretical representations about the role of micro level, so-called "dot kinetics" of dislocation interactions in lowering effects of localization of strain and embrittlement of materials.

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