CREEP OF Fe AND B.C.C. Fe-BASED ALLOYS UNDER INTERRUPTED IRRADIATION

L.N.Bystrov and A.B. Tsepelev *

The effect of cyclic electron irradiation on creep rate of Fe and Fe-base alloys is investigated. It is established that during transient irradiation periods (switching on or off the electron beam) a transient creep stage is observed ending up at a new steady state creep rate, normally lower than that before the transient stage onset. Thereby a cyclic irradiation regime is shown to have an advantage in creep suppressing in b.c.c. Fe-base alloys, as compared to a continuous irradiation regime. The nature of this effects is studied by analysing thermal activation energies.

INTRODUCTION

Ferritic steels use have a great potential for as structural materials for fast neutron nuclear reactors as well as for fusion reactors. Favourable properties of these steels are poor swelling tendency, low radiation creep rate, lack of higt temperature radiation embrittlement and good compatibility with liquid metallic heat-transfer agents, Davis (1). However, in order to realize such a great potential one has to have enough information on radiation resistance, including information on their deformation behaviour (i.e., creep) under cyclic irradiation as was mentioned by Bystrov et al (2).

Investigation of radiation behaviour of pure iron as well as of a number of iron-based alloys,

* Baikov Institute of Metallurgy, USSR Academy of Sciences, Leninsky Prosp., 49, 117911 Moscow, USSR

having just the same type of crystalline structure, as ferritic steels (i.e., b.c.c.), might be the proper base for clarifying this problem.

EXPERIMENTAL PROCEDURE

Investigation of creep of the materials chosen under cyclic electron irradiation was carried out with the help of the torque method of wire samples according to the experimental procedure described by Bystrov et al (3). The investigated temperature range was 200-500°C. The electron energy was 2 MeV and radiation intensity was $10^{13} sm^{-2} s^{-1}$. The temperature of samples during the experiments both in thermal and radiational conditions was automatically kept constant, with the accuracy not less than 1°C. During testing a creep activation energy ΔH was measured by the standard method of abrupt temperature change by 10° C.

The samples investigated were armco-iron (99.5 wt.%) and two iron-based alloys Fe-15Cr and Fe-4Cr--4V-4Al (all. wt.%) All materials were investigated in an annealed state (800°C for 2 hours) and Fe-Cr-V--Al alloy was, besides that, 50% coldworked.

RESULTS AND DISCUSSION

When cyclic electron irradiation impact on creep behavious of Fe and Fe-based alloys (b.c.c. lattice structure) was investigated, it was found, that the creep rate evolution during irradiation is of a very complicated form and is likely to depend upon both creep rate value itself and the sample strain value already accumulated (and maybe upon the irradiation fluence also). Tha characteristic example of typical creep rate time evolution for all the materials investigated is presented in Fig. 1. As is clearly seen from the figure, after a switch on of the electron beam an initial creep rate decrease is observed, followed by a rapide increase "spike" and a final decrease. After irradiation switch off the creep rate increases and then decreases down to a value, which is, as a rule, smaller than the initial thermal creep rate value, observed before the electron beam switch on. The value and duration of radiational creep rate "spike" varies depending upon the material tessed, the way it was processed and temperature, as well as in some cases it may by even absent. But in general the creep rate effectively deecreases under irradiation as clearly seen in Fig.2. Moreover, in Fe-Cr-V-Al alloy such a decrease is observed even on the accelerated creep stage, when monotonic creep rate increase during irradiation is stopped (Fig.3). Thus, radiation cycling might be the reason of a significant (10 times) decrease of b.c.c. Fe-based alloys creep rate as compared wich the original thermal creep rate value which had been observed before the irradiation was started. On example of such a hardening behaviour is presented in Fig.4, where a creep rate evolution of cold-worked Fe-Cr-V-Al alloy during consecutive short irradiation cycles (5 minutes irradiation + 5 minutes pause) is shown. It's clearly seen, that after the third irradiation cycle the creep rate value experienced a 30 times decrease, and then the material happened to be practically insensitive to the irradiation.

In order to clarify the physical nature of the phenomena observed Fe and Fe-based alloys creep mechanisms operating in thermal and radiation conditions were tentatively determined on the base of thermoactivation analysis results. It was found, that depending upon temperature, Fe thermal creep activation energy increase from $\sim$40 kcal/mole at 200°C up to $\sim$ 70 kcal/mole for the temperature range 300-400° C, which comes quite near to Fe self-diffusion activation energy value. In case of irradiation Fe creep activation energy at 200°C was 45-50 kcal/mole, and just after the electron beam was switched off it was 70-80 kcal/mole. But in 10-20 minutes after the beam switch off it decreased down to $\sim$ 40 kcal/mole.

Temperature dependence of thermal and radiation creep activation energy of Fe-Cr-V-Al alloy is shown in Fig.5. Within the experimental accuracy range no influence of the alloy pretreatment (either annealing or cold working) on activation energy value was observed. From the dependence presented the following three facts should be specially noted: monotonic Δ H value increase with temperature up to saturation at 350° C (thermal creep) and at 400°C (radiation creep); lower radiation creep activation energy as compared to thermal creep at temperatures below the temperature at which activation energy comes to saturation; lack of irradiation influence on creep activation energy value after the latter comes to saturation.

The investigations of Fe thermal creep characteristics here perfomed as well as the results of similar investigations carried cut by other researchers (Aliabev and Pavlov (4), Cadec et al (5) and Murty et al (6) enable us to conclude, that pure Fe thermal creep in the temperature range of 200-400°C is controlled by the gliding of jogged screw dislocations. Since Fe thermal creep activation energy at temperatures of 300-400°C is approximately, equal to bulk self-diffusion activation energy (~ 70 kcal/mole), we can assume, that the screw dislocation motion takes place via vacancies exchange between joggs of different types (either vacancies absorbing or emitting) by way of bulk diffusion. Activation energy decrease with temperature decrease in likely to be attributed to the increase of diffusion contribution by dislocation core into vacancies exchange between joggs. Similar considerations are likely to be valid for the alloys.

The influence of irradiation on creep thermal activation parameters as well as on creep rate, can be explained by introduction into the irradiated material of radiation point defects, which changes noticeably the diffusion-controlled dislocation motion kinetics. At the same time analizing currently available data, we can conclude, that while irradiation changes the interaction kinetics of dislocations with point defects, it doesn't change the presently operating creep mechanism. So, for example, even a very substantial increase of Fe creep activation energy just after the irradiation is discontinued (from 45-50 to 70-80 kcal/mole) can be explained quite reasonable by the same mechanism; while the material is still vacancies oversaturated just after the irradiation was discontinued the vacancies exchange between joggs on screw dislocations takes place via bulk diffusion. As radiation vacancies get more and more annealed the pipe diffusion by dislocation core, i.e. the process with lower activation energy, becomes prevailing.

The effect of general creep slowing down under irradiation agrees well with the creep mechanism proposed. As was shown earlier by Bystrov et al (7), an excess flux of highly mobile interstitials towards dislocations at the beginning of an irradiation cycle retards the jogged screw dislocations motion due to suppression of climb process of the joggs, which are supposed to absorbe vacancies . The fact, that during creep of iron to material structure consists mainly of screw dislocations is also confirmed by direct structural investigation (4).

Besides radiation creep rate time evolution, shown is Fig.1-3, depending upon actual creep rate value, temperature, as well as upon the total number of irradiation cycles (which corresponds to different values of both the sample's overall deformation and total fluence of irradiation) some other creep rate time dependences for the materials subjected to irradiation, including those characteristic for f.c.c. metals (2), can be produced. However, we are not going to address this problem here, since the objective of the present work is to demonstrate just specific pecularities of b.c.c. Fe-based alloys behaviour under cyclic irradiation. Let us note only that the impact of different factors upon the creep behaviour of Fe-based alloys can be possibily explained indirectly via their influence on the material structure and, as a consequence, on the controlling creep mechanism.

CONCLUSION

It's shown, that electron irradiation influences Fe and b.c.c. Fe-based alloys creep rate,first of all, through its influence on the interaction kinetics of dislocations with point defects, without changing substantially the operating creep mechanism. With Fe-Cr-V-Al taken as an example it's shown, that there is, at least in principle a possibility for development of high radiation durable ferritic steels.

REFERENCES

(1) Davis, J.W., J.Nucl.Mater.,Vol. 122,1984, pp.3-13.

(2) Bystrov, L.N., Ivanov, L.I. and Tsepelev, A.B., Rad. Eff., Vol.97, 1986, pp.127-149.

(3) Bystrov, L.N., Ivanov, L.I. and Tsepelev, A.B., Phil. Mag. A, Vol. 49, 1984, pp.273-285.

(4) Aliabev, V.M., and Pavlov, V.A., Phys.Stat.Sol. (a), Vol. 49, 1978, pp.509-515.

(5) Cadec, J., Pahutova, M.and Rys, P., Phys.Stat.Sol., Vol.36, 1969, pp.345-350.

(6) Murty, K.L., Gold,M. and Ruoff, A.L., J. Appl.Phys., Vol.41, 1970, pp.4917-4927.

(7) Bystrov, L.M., Ivanov, L.I. and Martishin, O.V., Rad. Eff., Vol.24, 1975, pp.111-115.

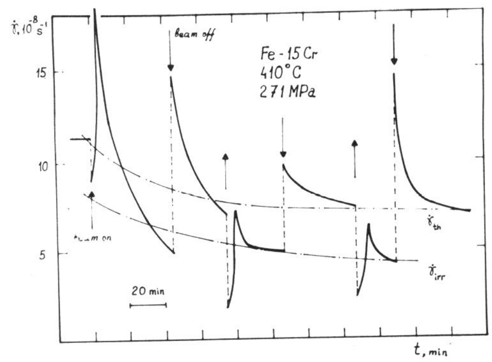

Figure 1 The creep rate ($\dot{\gamma}$) of Fe-15Cr alloy time evolution during cyclic electron irradiation

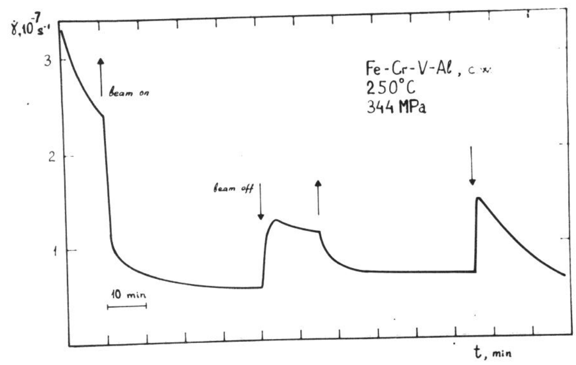

Figure 2 The creep rate ($\dot{\gamma}$) of Fe-Cr-V-Al alloy time evolution during cyclic electron irradiation

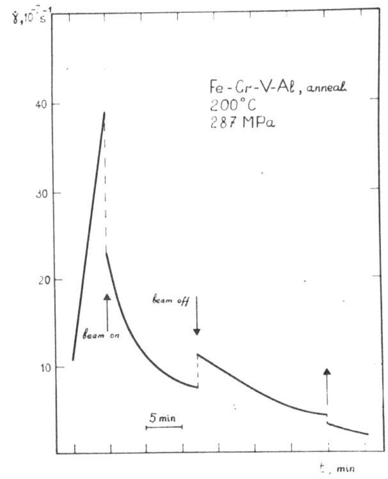

Figure 3 The change of character of the creep

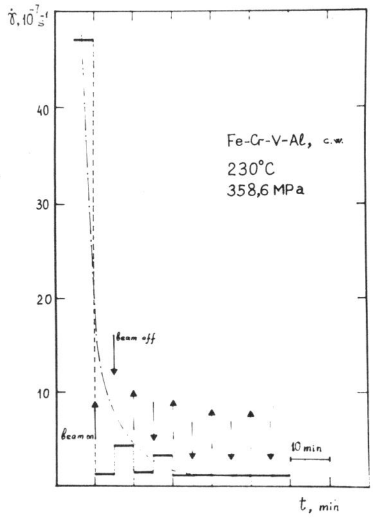

Figure 4 The creep retardation under irradiation

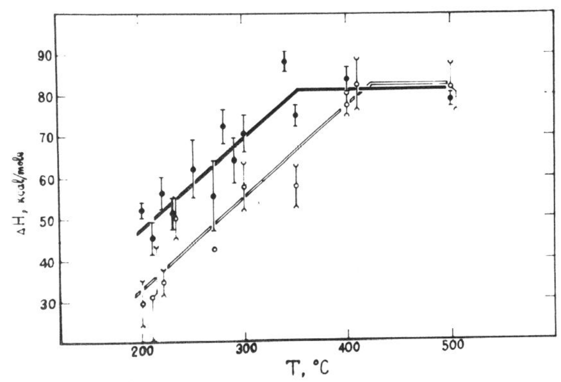

Figure 5 The activation energy vs. temperature for thermal (●) and radiation (○) Fe-Cr-V-Al creep