



Physical and mechanical modeling of the neutron irradiation effect on ductile fracture. Part 2. Prediction of swelling effect on drastic decrease in strength



Boris Margolin*, Alexander Sorokin

Central Research Institute of Structural Materials "Prometey", Saint-Petersburg, Russia

ARTICLE INFO

Article history:

Received 4 July 2013

Accepted 20 May 2014

Available online 2 June 2014

ABSTRACT

A drastic decrease in the ultimate tensile strength of irradiated austenitic steels with high swelling values is considered.

The physical–mechanical model proposed in Part 1 of the present paper is applied for the prediction of a drastic decrease in ultimate tensile strength. The mechanism called by the authors the “running collapse mechanism” is used for modeling the material ductile fracture when stresses are less than the yield strength. This ductile mechanism is similar to brittle fracture when crack propagates unstable manner.

Running collapse mechanism occurs due to evolution of vacancy voids resulting in irradiation swelling. Nanoscale of vacancy voids (void sizes, distance between voids) results in the possibility of ductile fracture in very small zones whose size is considerably smaller than the grain size.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

There are a number of papers [1–3] devoted to experimental investigation of the swelling effect on ultimate strength σ_{ul} of irradiated austenitic steels. According to the paper [1], at a certain swelling S a drastic decrease in ultimate tensile strength begins at transcrystalline fracture by the mechanism of growth and coalescence of vacancy voids. The decrease of σ_{ul} may reach 5 times over a short range of a swelling variation.

Fig. 1 shows the data obtained for 18Cr–10Ni–Ti steel with high carbon content (0.11 wt.%) irradiated at the temperature $T_{irr} = 400$ –500 °C and tested at the temperature $T_{test} = T_{irr}$ [1]. According to the results presented, σ_{ul} decreases 5 times over the swelling range from 17% to 27%, and the specimens fracture occurs at stresses lower than the yield strength σ_Y .

At present, there are scarcely any adequate physical models explaining the sharp decrease in σ_{ul} . Let us consider some of the existing explanations.

The widespread explanation of such behavior of material is reduction of specimen net cross-section due to vacancy voids [1]. This explanation cannot be a satisfactory for the following reason.

It is known that at ductile fracture the ultimate tensile strength for a specimen with voids is higher than for a void-free specimen when both the specimens have the same net cross-section area. Such result is connected with a higher stress state triaxiality (SST) in a specimen with voids.

Therefore the value σ_{ul} of a specimen with the swelling S with uniform distribution of vacancy voids over a specimen volume [4] should be at least no lower than

$$\sigma_{ul} = (1 - \bar{A}_v) \cdot \sigma_{ul}^m, \quad (1)$$

where $\bar{A}_v$ is the relative area of vacancy voids (the ratio of voids cross-section area to the cross-section area of a specimen with voids) resulting in irradiation swelling, σ_{ul}^m is the ultimate tensile strength of a matrix material (a material without vacancy voids).

The dependence of σ_{ul}^m on the neutron dose D is a monotonically increasing one due to increasing the concentration of radiation defects (dislocation loops and precipitates). With neutron doses corresponding to a drastic decrease in σ_{ul} ($D > 40$ dpa) σ_{ul}^m reaches its maximum value and does not grow any more [4]. Thus a decrease in ultimate tensile strength with swelling changing from 17% to 27% can be calculated by the formula:

$$\frac{\sigma_{ul}|_{S=27\%}}{\sigma_{ul}|_{S=17\%}} = \frac{(1 - \bar{A}_v)|_{S=27\%}}{(1 - \bar{A}_v)|_{S=17\%}}, \quad (2)$$

* Corresponding author. Tel.: +7 812 710 25 38.

E-mail addresses: margolin@prometey2.spb.su, margolinbz@yandex.ru (B. Margolin).

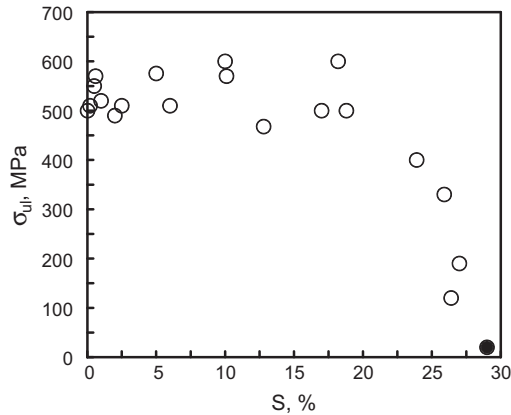


Fig. 1. Dependence of ultimate strength on swelling for 18Cr–10Ni–Ti steel with high carbon content (0.11 wt.%) for $T_{\text{test}} = T_{\text{irr}} = 400\text{--}500\text{ }^{\circ}\text{C}$: ○, ● are experimental data [1] (black dot corresponds to specimen with flaw).

The swelling level of 17% corresponds to the upper limit of swelling at which there is still no drastic decrease of ultimate tensile strength according to [1]. The swelling level of 27% corresponds to a decrease of ultimate tensile strength by 5 times.

To determine the relation between $\bar{A}_v$ and S we will use the following simplified statements: all voids of a cubic form with the same size are located in cube corners, i.e. they are spaced at equal intervals. Then

$$S = \frac{d_{\text{vac}}^3}{l_{\text{vac}}^3 - d_{\text{vac}}^3}, \quad (3)$$

where d_{vac} is the average size of a vacancy voids, l_{vac} is the average distance between centers of voids.

From Eq. (3) we have

$$\bar{A}_v = \frac{d_{\text{vac}}^2}{l_{\text{vac}}^2} = \left(\frac{S}{1+S} \right)^{2/3}, \quad (4)$$

Using Eqs. (2) and (4) let us calculate a possible decrease in σ_{ul} with swelling changing from 17% to 27%:

$$\frac{\sigma_{\text{ul}}|_{S=27\%}}{\sigma_{\text{ul}}|_{S=17\%}} \cong 0.89.$$

Thus a several times decrease in σ_{ul} cannot be explained only by an increase in voids area when increasing swelling from 17% to 27%.

Considerable progress was made in the understanding of the swelling effect on ultimate tensile strength of material in papers [2,3]. The voids coalescence areas were revealed (see Fig. 2) when investigating voids distribution by a transmission electron microscope. Such result was interpreted by the authors [2,3] as the possibility of spontaneous voids coalescence in material under irradiation.

In paper [2] on the basis of the so-called “sphere problem” [5] the authors introduced the parameter Ω as a ratio of the sum of volumes of all spheres to the volume of a material with spheres. When Ω reaches some critical value Ω_c , the situation is possible when each sphere includes the center of a neighboring sphere. In this case the coalescence of spheres with the radius R_c can occur. The numerical value of the parameter Ω_c is 2.7 [6].

Then it is assumed [2] that voids of the radius $R = R_c/2$ can also coalesce spontaneously by contacting each other. Thus the critical void volume fraction $f_c = \Omega_c \left(\frac{R}{R_c} \right)^3 = \Omega_c/8 = 0.34$ where the void volume fraction is the ratio of the volume of voids to the volume of a material with voids.

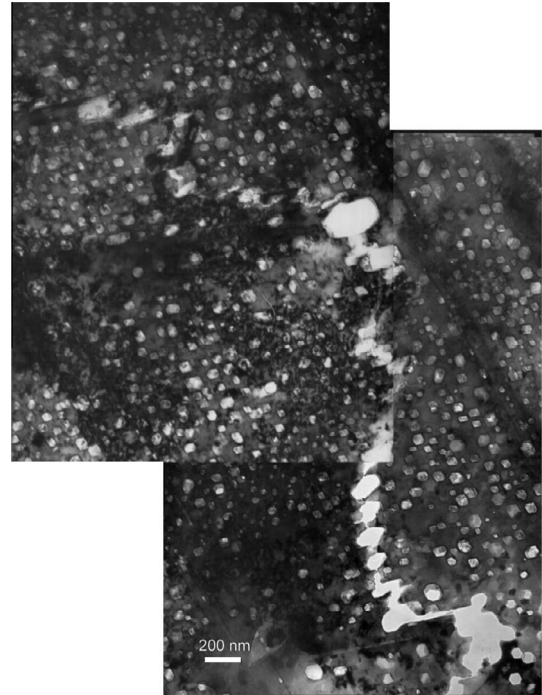


Fig. 2. Voids coalescence area in the specimen of 16Cr–15Ni–2Mo–2Mn–Ti–V–B steel (ChS-68) irradiated by the neutron dose $D = 67\text{ dpa}$ at $T_{\text{irr}} = 475\text{ }^{\circ}\text{C}$; void volume fraction is $\sim 9\%$ [2].

Void volume fraction f can be calculated by the formula

$$f = \left(\frac{d_{\text{vac}}}{l_{\text{vac}}} \right)^3. \quad (5)$$

According to Eqs. (3) and (5) $S = f/(1-f)$. Then the value of $f_c = 0.34$ corresponds to $S_c = 0.52$.

Using the introduced parameter f_c the dependence $\sigma_{\text{ul}}(f)$ is presented in paper [2] in the following form

$$\sigma_{\text{ul}} = \sigma_{\text{ul}}^m \left[1 - \left(\frac{f}{f_c} \right)^{2/3} \right]. \quad (6)$$

Based on Eqs. (3) and (5) the Eq. (6) can be represented in the form

$$\sigma_{\text{ul}} = \sigma_{\text{ul}}^m \left[1 - \left(\frac{\bar{A}_v}{\bar{A}_v^c} \right)^2 \right]. \quad (7)$$

As is seen, Eq. (7) describes a linear decrease in σ_{ul} with a growth of $\bar{A}_v$ beginning with $\bar{A}_v = 0$.

On the basis of the model analysis [2,3], the following conclusion may be made. The model does not allow one to describe the experimentally observed peculiarity of the dependence $\sigma_{\text{ul}}(S)$, i.e., a drastic decrease in σ_{ul} over a short range of a swelling increase. According to the model, a decrease in σ_{ul} proceeds monotonically beginning with $S = 0$.

Moreover, the model vulnerability consists in the assumption that two events are identical: they are the coalescence of several vacancy voids and specimen fracture [2,3]. It is clear that the nucleation of a local flaw 1–3 μm in size does not necessarily mean specimen fracture, especially if the fracture proceeds by the ductile mechanism due to the growth and coalescence of voids.

Thus the object of this paper is to investigate a cause of a drastic decrease in ultimate tensile strength σ_{ul} and to apply the physical–mechanical model presented in the Part 1 of the present

Download English Version:

<https://daneshyari.com/en/article/1565154>

Download Persian Version:

<https://daneshyari.com/article/1565154>

[Daneshyari.com](https://daneshyari.com)