INFLUENCE OF RADIATION-INDUCED VOIDS AND BUBBLES ON PHYSICAL PROPERTIES OF AUSTENITIC STRUCTURAL ALLOYS

—E. N. Shcherbakov, A. V. Kozlov, and I. A. Portnykh (FSUE Institute of Nuclear Materials), Iouri I. Balachov (SRI International), and F. A. Garner (Pacific Northwest National Laboratory)*

OBJECTIVE

The object of this effort is to determine experimentally the effect of radiation-induced microstructural changes on the physical properties of austenitic structural alloys.

SUMMARY

Void swelling in austenitic stainless steels induces significant changes in their electrical resistivity and elastic moduli, as demonstrated in this study using a Russian stainless steel irradiated as fuel pin cladding in BN-600. Precipitation induced by irradiation also causes second-order changes in these properties. When cavities are full of helium as expected under some fusion irradiation conditions, additional second-order changes are expected but they will be small enough to exclude from the analysis.

PROGRESS AND STATUS

Introduction

Void swelling is known to influence not only the dimensional stability of irradiated stainless steels, but also many of its basic physical properties. Recently, there has been a focus in the light water reactor community on measurement of void-induced changes in electrical resistivity, elastic moduli and ultrasonic velocity, and to use these measurements to measure swelling nondestructively [1-3].

Electrical resistivity changes were used earlier in the fusion materials program as a method to estimate the swelling-induced changes of thermal resistivity for high heat flux components [4]. It now appears that nondestructive applications of changes in this and other important physical properties may be useful for stainless steels chosen for use in the fusion energy program. As shown in this study, there are other microstructural contributions to changes in physical properties that must be taken into consideration.

Experimental Details

Fuel element cladding tubes (6.9 mm initial outer diameter and thickness 0.4 mm) constructed from 20% cold-worked austenitic steel of nominal composition 0.1C-16Cr-15Ni-2Mo-lMn that had been irradiated in the BN-600 fast reactor were examined after defueling and cleaning. Specimens of 30 mm length were cut from various areas to obtain a variety of temperatures (430 - 590°C), dose levels (50 to 90 dpa) and swelling values as high as 23%.

The electrical resistivity *R* was measured for each specimen at room temperature using a technique in which the potential difference between standard and test specimens was determined. The procedure of electrical resistivity measurements was described in detail in [5]. The relative measurement error did not exceed 1%.

To measure Young's modulus *E* and the shear modulus *G* an ultrasonic resonant technique was utilized which is based on both excitation of ultrasonic vibrations and measurement of natural frequencies of longitudinal and shear vibrations in the test specimen [6]. The magnitudes of both moduli were calculated based on dynamic elasticity theory using measured values of resonant frequencies and specimen sizes. Measurement error of the moduli did not exceed 1%.

---

* Pacific Northwest National Laboratory (PNNL) is operated for the U.S. Department of Energy by Battelle Memorial Institute under contract DE-AC06-76RLO-1830.

Void swelling S was determined from density measurements obtained using a hydrostatic weighing technique.

$$S = \left(\delta_0 / \delta - 1\right) \cdot 100\% , \qquad (1)$$

δ_0 and δ are the density in the initial state and after irradiation, respectively, with a measurement error of ± 0.02 g/cm^3.

Results

An earlier report presented the first results on this project, which has now been completed [7]. Results of electrical resistivity measurements and determination of Young's modulus *E* and shear modulus *G* are shown in Figures 1-3. The dependence of these physical properties on void swelling is clearly demonstrated. One can see also some deviations from expected behavior that may reflect experimental problems or may be connected with other structural changes. As radiation-induced structural changes are usually dependent on irradiation temperature the data were separated into two sets: "high-temperature" (>520°C) and "low-temperature" (<520°C).

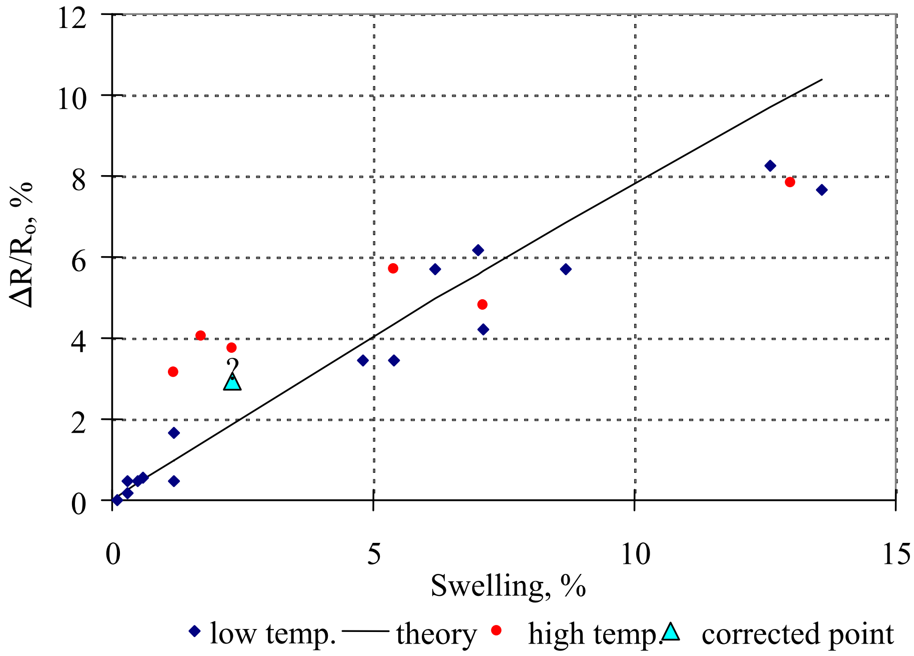

Figure 1. Dependence of relative change in electrical resistivity on void swelling. One point at 2.2% swelling shows the correction that would arise when accounting for nickel segregation into precipitates.

Discussion

As was shown in [6] voids in the two-phase model can be considered as a second phase with zero values of electrical conductivity and elastic modulus. Relative change can are defined in the following analytical expressions assuming an invariance of physical and mechanical properties of the matrix material.

$$\frac{\Delta R}{R_0} = \frac{5 \cdot S}{4 \cdot S + 6} \qquad (2)$$

$$\frac{\Delta E}{E_0} = \frac{1}{(1+S)^2} - 1 \qquad (3)$$

$$\frac{\Delta G}{G_0} = \frac{1}{(1+S)^2} - 1 \qquad (4)$$

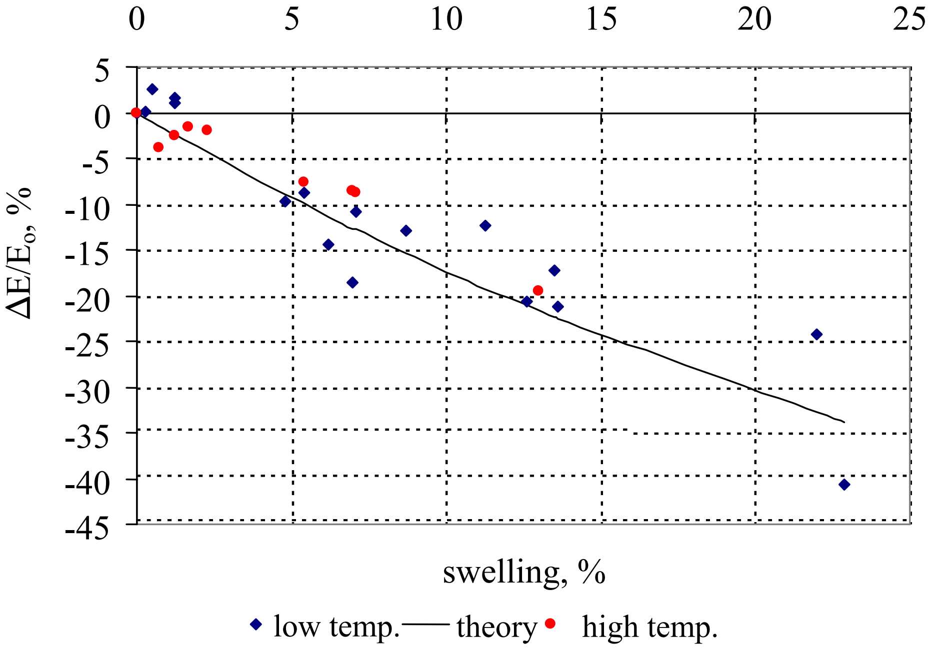

Figure 2. Dependence of relative change in Young's modulus on void swelling.

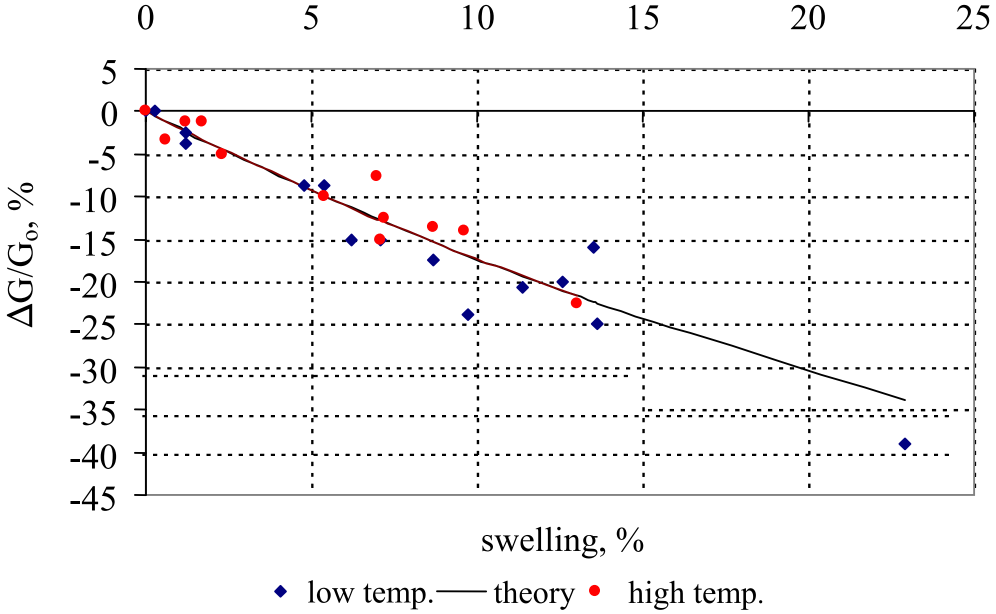

Figure 3. Dependence of relative change in shear modulus on void swelling.