219
12-3 2

DWR-1641

MASTER

WADCO
CORPORATION

a subsidiary of Westinghouse Electric Corporation
Post Office Box 1970
Richland, Washington 99352

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

P7701

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

LEGAL NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

HANFORD ENGINEERING DEVELOPMENT LABORATORY

Richland, Washington
operated by

WADCO CORPORATION

A Subsidiary of Westinghouse Electric Corporation
for the

United States Atomic Energy Commission Under Contract No. AT(45-1)-2170

A NOTE ON THE INTERDEPENDENCY
OF SWELLING, VOID DIAMETER
AND VOID NUMBER DENSITY IN ANNEALED
AISI TYPE 304 STAINLESS STEEL

J. L. Straalsund and J. F. Bates

THIS DOCUMENT CONFIRMED AS
UNCLASSIFIED
DIVISION OF CLASSIFICATION
BY J. H. Kahn / amh
DATE 12/10/70

October 1970

FIRST UNRESTRICTED
DISTRIBUTION MADE

NOV 18 '70

LEGAL NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

WADCO
CORPORATION
Richland, Washington 99352

UNCLASSIFIED

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Printed in the United States of America
Available from
National Technical Information Service
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

A NOTE ON THE INTERDEPENDENCY OF SWELLING,
VOID DIAMETER AND VOID NUMBER DENSITY
IN ANNEALED AISI TYPE 304 STAINLESS STEEL

J. L. Straalsund and J. F. Bates

ABSTRACT

This note describes the development of a set of three mutually consistent empirical equations describing void number density, void diameter, and swelling (or void volume) as a function of fluence and temperature. The equation for swelling reflects trends consistent with available transmission electron microscopy data.

**THIS PAGE
WAS INTENTIONALLY
LEFT BLANK**

TABLE OF CONTENTS

ABSTRACT	iii
LIST OF FIGURES	v
INTRODUCTION	1
DISCUSSION	2
REFERENCES	4
DISTRIBUTION	Distr-1

LIST OF FIGURES

1. Temperature Dependence of the Slopes of Parameter Versus Fluence Plots	5
2. Temperature Dependence of χ in 304 Stainless Steel	5
3. Void Number Density in AISI 304 SS (370 to 380°C).	6
4. Void Number Density in AISI 304 SS (420 to 440°C).	7
5. Swelling in AISI 304 SS (370 to 380°C)	8
6. Swelling in AISI 304 SS (420 to 440°C)	9

A NOTE ON THE INTERDEPENDENCY OF SWELLING,
VOID DIAMETER AND VOID NUMBER DENSITY
IN ANNEALED AISI TYPE 304 STAINLESS STEEL

J. L. Straalsund and J. F. Bates

INTRODUCTION

One of the most important areas under consideration in the development of LMFBR concepts is irradiation-induced volume change, or swelling, of structural materials. Swelling is a consequence of void formation in irradiated material and is assumed here to be equal to the total volume of the voids formed. There are two direct experimental approaches or methods for investigating this phenomenon. One is transmission electron microscopy (TEM), whereby the number of voids of all given sizes is determined; from such data the total void volume is calculated. The second approach utilizes changes in the bulk densities or the macroscopic dimensions of specimens determined by measurements before and after irradiation. An immediate problem which then presents itself is the synthesis of data from these two types of measurements. Bulk density data is generally more accurate than the TEM data for large changes in volume ($>0.5\%$), and moreover, is more easily obtained. Consequently, bulk density data has usually been used in the development of empirical swelling equations for design purposes.^(1,2) The current extensive effort on metal swelling however is generating an increasing amount of TEM data which, for small changes in volume, may be expected to be more accurate than bulk density data. Both the void number density and void diameter, available from TEM measurements, show important trends which are not disclosed by the bulk density data. Thus, additional confidence may be placed on the reliability of an

empirical equation for swelling if the equation reflects trends consistent with the TEM data. This note describes the development of a set of three mutually consistent empirical equations describing void number density, void diameter, and swelling (or void volume) as a function of fluence and temperature.

DISCUSSION

The trend of void number density decreasing with increasing temperature was evaluated by classifying TEM data and bulk density data according to temperature at 20°C intervals. The data utilized is presented elsewhere.⁽³⁾ For each of these intervals the logarithms of the diameter, number density, and percent volume change were plotted against the logarithm of the fluence ($E > 0.1$ MeV). Straight lines were drawn through the data points of each of these three categories. The slopes of these lines are shown in Figure 1. The slopes increased with temperature from 370 to 470°C for both void number density and swelling. The slope was fairly constant through the void diameter data. The logarithm of the intercept, at a fluence of 10^{22} n/cm², varied linearly with temperature for void number density and linearly with $1/T$ for void diameter.

The slopes and intercepts of these lines were then adjusted to comply with the physical and geometric constraint:

$$\% \frac{\Delta V}{V} = K \rho d^3 \quad (1)$$

where $\% \frac{\Delta V}{V} = \% \text{ Volume Change}$

$\rho = \text{Void Number Density, cm}^{-3} \times 10^{-15}$

$d = \text{Void Diameter, } \text{\AA}$

$K = \text{Physical and Proportionality Factor}$

The fluence independent factor K incorporates an assumed spherical shape of the voids, the conversion of units, and the ratio of the average cubed diameter to the cube of the average diameter χ . The relationship between χ and temperature is shown in Figure 2 for AISI 304 SS. Using the above mentioned units and the relationship described in Figure 2, Equation (1) becomes (2).

$$\% \frac{\Delta V}{V} = [(T - 40) \times 10^{-10}] \rho d^3 \quad (T = ^\circ K) \quad (2)$$

The three equations are then best described as:

$$d = (\phi t)^{0.15 - 24/\theta^2} \exp(7.45 - 1700/T) \quad (3)$$

$$\rho = (\phi t)^{1.60 - 27/\theta + 150/\theta^2} \exp(10.25 - 0.015T) \quad (4)$$

$$\% \frac{\Delta V}{V} = [(T - 40) \times 10^{-10}] (\phi t)^{2.05 - 27/\theta + 78/\theta^2} \exp(32.60 - 5100/T - 0.015T) \quad (5)$$

where $(\phi t) = n/\text{cm}^2 \times 10^{-22}$ ($E > 0.1$ MeV)

$T = ^\circ K$

$\theta = (T - 623.)$

As these equations were developed on an empirical basis, extrapolation beyond the range of available data is not suggested.

The equations may be considered reliable between 370°C and 500°C for fluences less than $7 \times 10^{22} \text{ n/cm}^2$.

Void number density in the 370 to 380°C and 420 to 440°C temperature ranges is shown in Figures 3 and 4, and the corresponding swelling is shown in Figures 5 and 6. Also included on the $\frac{\Delta V}{V}$ plots are the lines representing an equation developed by a least-mean-squares fit of bulk density data only: (2)

$$\% \frac{\Delta V}{V} = 4.9 \times 10^{-49} (\phi t)^{1.71} 10^4 [1.55 \times 10^4 / T - 5.99 \times 10^6 / T^2] \quad (6)$$

where $(\phi t) = n/\text{cm}^2$

$T = ^\circ\text{K}$

This equation contains no temperature dependent fluence exponent because no temperature dependency for the exponent is apparent from density measurements alone. It will be noted from the plots in Figures 5 and 6 that both Equations (5) and (6) describe the data well. The principal difference between Equations (5) and (6) is that different values for swelling will be obtained by extrapolation of the data to higher fluences. Equation (5) is preferred because it reflects trends in the microstructural parameters ρ and d .

REFERENCES

1. S. Oldberg, D. Sandusky, P. E. Bohaboy, and F. A. Comprelli. "Analysis of Swelling of Austenitic Stainless Steels in Fast Reactors," Trans Am Nucl Soc, vol 12, no. 2, p. 588. 1969.
2. T. T. Claudson, R. W. Barker, and R. L. Fish. "The Effects of Fast Flux Irradiation on the Mechanical Properties and Dimensional Stability of Stainless Steel," Nucl Appl and Tech, vol 9, no. 1, p. 10. July 1970.
3. H. R. Brager, J. L. Straalsund, J. J. Holmes, and J. F. Bates. WADCO Corporation, Richland, Washington. "Fast Reactor Irradiation Induced Defect Formation in Austenitic Stainless Steels". To be published.

NEG. 701682-3

FIGURE 1. Temperature Dependence of the Slopes of Parameter Versus Fluence Plots

NEG. 702236-5

FIGURE 2. Temperature Dependence of χ in 304 Stainless Steel

NEG. 702440-3

FIGURE 3. Void Number Density in AISI 304 SS

NEG. 6702440-4

FIGURE 4. Void Number Density in AISI 304 SS

NEG. 702440-2

FIGURE 5. Swelling in AISI 304 SS

NEG. 702440-1

FIGURE 6. Swelling in AISI 304 SS

DISTRIBUTION

No. of
Copies

OFFSITE

1	<u>AEC Chicago Patent Group</u>
G. H. Lee, Chief
26	<u>AEC Division of Reactor Development and Technology</u>
Director, RDT
Asst Dir for Nuclear Safety
Analysis & Evaluation Br, RDT:NS
Asst Dir for Plant Engrg, RDT
Facilities Br, RDT:PE
Components Br, RDT:PE
Instrumentation & Control Br, RDT:PE
Liquid Metal Systems Br, RDT:PE
Asst Dir for Program Analysis, RDT
Asst Dir for Project Mgmt, RDT
Liquid Metals Projects Br, RDT:PM
FFTF Project Manager, RDT:RE
Asst Dir for Reactor Engrg, RDT
Control Mechanisms Br, RDT:RE
Core Design Br, RDT:RE (2)
Fuel Engineering Br, RDT:RE
Fuel Handling Br, RDT:RE
Reactor Vessels Br, RDT:RE
Coolant Chemistry Br, RDT:RT
Fuel Recycle Br, RDT:RT
Fuels & Materials Br, RDT:RT
Reactor Physics Br, RDT:RE
Special Technology Br, RDT:RT
Asst Dir for Engrg Standards, RDT
LMFBR Program Manager, RDT:PM
1	<u>AEC Idaho Operations Office</u>
Nuclear Technology Division
C. W. Bills, Director
1	<u>AEC San Francisco Operations Office</u>
Director, Reactor Division

No. of
Copies

5 AEC Site Representatives
 Argonne National Laboratory - CH
 Atomics International
 Westinghouse Electric Corp.
 General Electric Company
 Argonne National Laboratory - ID

226 AEC Division of Technical Information Extension

3 Argonne National Laboratory
 R. A. Jaross
 LMFBR Program Office
 N. J. Swanson

1 Atomic Power Development Association
 Document Librarian

5 Atomics International
 FFTF Program Office

1 Liquid Metal Engineering Center
 R. W. Dickinson

2 Liquid Metal Information Center
 A. E. Miller

2 Babcock & Wilcox Company
 Atomic Energy Division
 S. H. Esleeck
 G. B. Garton

1 WADCO Representative
 R. M. Fleischman (ZPPR)

1 Combustion Engineering
 1000 MWe Follow-On Study
 W. P. Staker, Project Manager

1 Combustion Engineering
 Mrs. Nell Holder, Librarian

No. of
Copies

5	<u>General Electric Company</u> Advanced Products Operation Karl Cohen (3)
1	<u>General Electric Company</u> Nucleonics Laboratory Dr. H. W. Alter, Mgr. P. O. Box 846 Pleasanton, Calif. 94566
2	<u>Gulf General Atomic Inc.</u> General Atomic Division D. Coburn
1	<u>Idaho Nuclear Corporation</u> J. A. Buckham
2	<u>Oak Ridge National Laboratory</u> W. O. Harms
1	<u>Stanford University</u> Nuclear Division Division of Mechanical Engrg R. Sher
1	<u>United Nuclear Corporation</u> Research and Engineering Center R. F. DeAngelis
5	<u>Bechtel Corporation</u> J. J. Teachnor
10	<u>Westinghouse Electric Corporation</u> Atomic Power Division Advanced Reactor Systems D. C. Spencer

No. of
CopiesONSITE

2	<u>RDT Asst Dir for Pacific Northwest Programs</u>	
1	<u>AEC Richland Operations Office</u> J. M. Shivley	
1	<u>AEC Chicago Patent Group</u> R. K. Sharp (Richland)	
7	<u>Battelle-Northwest</u> J. M. Batch BNW Technical Information Files (5) BNW Technical Publications (1)	
1	<u>Bechtel Corporation</u> W. A. Smith (Richland)	
86	<u>WADCO Corporation</u>	
	G. J. Alkire	W. B. McDonald
	H. J. Anderson	J. S. McMahon
	S. O. Arneson	J. M. Norris
	J. M. Atwood	H. N. Pedersen
	J. F. Bates (20)	R. E. Peterson
	C. P. Cabell	B. G. Rieck
	J. R. Carrell	W. E. Roake
	J. C. Cochran	G. J. Rogers
	G. S. Cochrane	W. F. Sheely
	W. H. Esselman	J. L. Straalsund (20)
	E. A. Evans	C. D. Swanson
	W. M. Gajewski	K. G. Toyoda
	E. N. Heck	L. D. Turner
	K. M. Harmon	B. Wolfe
	P. L. Hofmann	W. R. Wykoff
	J. N. Judy	WADCO Document Control (15)
	F. J. Leitz	WADCO Tech Pubs (703)