Zirconium in the Nuclear Industry

Eleventh International Symposium

E. Ross Bradley
George P. Sabol
Editors

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Zirconium in the Nuclear Industry: Eleventh International Symposium

E. Ross Bradley and George P. Sabol, editors

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Foreword

The Eleventh International Symposium on Zirconium in the Nuclear Industry was held in Garmisch-Partenkirchen, Germany on 11–14 Sept. 1995. The sponsor of the event was ASTM Committee B-10 on Reactive and Refractory Metals and Alloys.

The symposium chairman was E. Ross Bradley, Sandvik Special Metals Corporation, the symposium co-chairman was Erich Tenckhoff, Siemens AG, and the editorial chairman was George P. Sabol, Westinghouse Electric Corporation. Serving as editors of this publication were E. Ross Bradley and George P. Sabol.

Contents

Overview xi

KROLL AWARD PAPERS

Learning from History: A Case Study in Nuclear Fuel—J. A. L. ROBERTSON 3

Behavior and Properties of Zircaloys in Power Reactors: A Short Review of Pertinent Aspects in LWR Fuel—F. GARZAROLLI, H. STEHLE, AND E. STEINBERG 12

CORROSION MECHANISMS—I

Microstructure of Oxides on Zircaloy-4, 1.0Nb Zircaloy-4, and Zircaloy-2 Formed in 10.3-MPa Steam at 673 K—H. ANADA AND K. TAKEDA 35
Discussion 54

The Importance of Oxide Morphology for the Oxidation Rate of Zirconium Alloys—G. WIKMARK, P. RUDLING, B. LEHTINEN, B. HUTCHINSON, A. OSCARSSON, AND E. AHLBERG 55
Discussion 73

Effect of Annealing Temperature on Corrosion Behavior and ZrO_2 Microstructure of Zircaloy-4 Cladding Tube—H. ANADA, B. J. HERB, K. NOMOTO, S. HAGI, R. A. GRAHAM, AND T. KURODA 74
Discussion 92

Microstructure of Oxide Films Formed during the Waterside Corrosion of the Zircaloy-4 Cladding in Lithiated Environment—D. PÊCHEUR, J. GODLEWSKI, P. BILLOT, AND J. THOMAZET 94
Discussion 113

Mechanisms of LiOH Degradation and H_3BO_3 Repair of ZrO_2 Film—B. COX, M. UNGURELU, Y.-M. WONG, AND C. WU 114
Discussion 136

PWR Zircaloy Fuel Cladding Corrosion Performance, Mechanisms, and Modeling—B. CHENG, P. M. GILMORE, AND H. H. KLEPFER 137
Discussion 159

Corrosion Mechanisms—II

Correlation Between Electrochemical Properties and Corrosion Resistance of Zirconium Alloys—Y. ITO AND T. FURUYA 163
Discussion 180

Long-Term In Situ Corrosion Investigation of Zr Alloys in Simulated PWR Environment by Electrochemical Measurements—H. GÖHR, J. SCHALLER, H. RUHMANN, AND F. GARZAROLLI 181
Discussion 202

Anodic Protection Provided by Precipitates in Aqueous Corrosion in Zircaloy—T. ISOBE, T. MURAI, AND Y. MAE 203
Discussion 217

Investigation of In-Pile Grown Corrosion Films on Zirconium-Based Alloys—O. GEBHARDT, A. HERMANN, G. BART, H. BLANK, F. GARZAROLLI, AND I. L. F. RAY 218
Discussion 241

Microstructure Evolutions and Iron Redistribution in Zircaloy Oxide Layers: Comparative Effects of Neutron Irradiation Flux and Irradiation Damages—X. ILTIS, F. LEFEBVRE, AND C. LEMAIGNAN 242
Discussion 263

Oxide Characteristics and Corrosion and Hydrogen Uptake in Zr-2.5 Nb CANDU Pressure Tubes—B. D. WARR, P. A. W. VAN DER HEIDE, AND M. A. MAGUIRE 265
Discussion 291

Corrosion and Hydrogen Effects

The Effect of the Trace Impurity Uranium on PWR Aqueous Corrosion of Zircaloy-4—H. R. PETERS AND J. L. HARLOW 295
Discussion 317

Detrimental Role of Hydrogen on the Corrosion Rate of Zirconium Alloys—M. BLAT AND D. NOEL 319
Discussion 336

Hydrogen Pickup and Redistribution in Alpha-Annealed Zircaloy-4—B. G. KAMMENZIND, D. G. FRANKLIN, H. R. PETERS, AND W. J. DUFFIN 338
Discussion 370

Ex-Reactor Mechanical Behavior

A Unified Model to Describe the Anisotropic Viscoplastic Behavior of Zircaloy Cladding Tubes—P. DELOBELLE, P. ROBINET, P. BOUFFIOUX, P. GEYER, AND I. LE PICHON 373
Discussion 393

The Influence of Temperature and Yield Strength on Delayed Hydride Cracking in Hydrided Zircaloy-2—P. EFSING AND K. PETTERSSON 394
Discussion 404

IN-REACTOR MECHANICAL BEHAVIOR

Effects of Hydride Precipitate Localization and Neutron Fluence on the Ductility of Irradiated Zircaloy-4—A. M. GARDE, G. P. SMITH, AND R. C. PIREK 407
Discussion 429

Fracture Toughness of Zircaloy Cladding Tubes—V. GRIGORIEV, B. JOSEFSSON, AND B. ROSBORG 431
Discussion 447

A Model for Analysis of the Effect of Final Annealing on the In- and Out-of-Reactor Creep Behavior of Zircaloy Cladding—M. LIMBÄCK AND T. ANDERSSON 448
Discussion 468

Properties of an Irradiated Heat-Treated Zr-2.5 Nb Pressure Tube Removed from the NPD Reactor—C. K. CHOW, C. E. COLEMAN, M. H. KOIKE, A. R. CAUSEY, C. E. ELLS, R. R. HOSBONS, S. SAGAT, V. F. URBANIC, AND D. K. RODGERS 469
Discussion 491

Link Between Results of Small- and Large-Scale Toughness Tests on Irradiated Zr-2.5Nb Pressure Tube Material—P. H. DAVIES AND R. S. W. SHEWFELT 492
Discussion 517

Modeling In-Reactor Deformation of Zr-2.5Nb Pressure Tubes in CANDU Power Reactors—N. CHRISTODOULOU, A. R. CAUSEY, R. A. HOLT, C. N. TOMÉ, N. BADIE, R. J. KLASSEN, R. SAUVÉ, AND C. H. WOO 518
Discussion 537

EFFECT OF IRRADIATION ON MICROSTRUCTURE

Effect of In-PWR Irradiation on Size, Structure, and Composition of Intermetallic Precipitates of Zr Alloys—F. GARZAROLLI, W. GOLL, A. SEIBOLD, AND I. RAY 541
Discussion 555

In Situ Studies of Phase Transformations in Zirconium Alloys and Compounds Under Irradiation—A. T. MOTTA, J. A. FALDOWSKI, L. M. HOWE, AND P. R. OKAMOTO 557
Discussion 579

Evolution of Microstructure in Zirconium Alloys During Irradiation—M. GRIFFITHS, J. F. MECKE, AND J. E. WINEGAR 580
Discussion 602

Influence of Neutron Irradiation on Dislocation Structure and Phase Composition of Zr-Base Alloys—V. N. SHISHOV, A. V. NIKULINA, V. A. MARKELOV, M. M. PEREGUD, A. V. KOZLOV, S. A. AVERIN, S. A. KOLBENKOV, AND A. E. NOVOSELOV 603
Discussion 622

Non-Linear Irradiation Growth of Cold-Worked Zircaloy-2—R. A. HOLT, A. R. CAUSEY, N. CHRISTODOULOU, M. GRIFFITHS, E. T. C. HO, AND C. H. WOO 623
Discussion 637

Influence of Iron in the Nucleation of ⟨c⟩ Component Dislocation Loops in Irradiated Zircaloy-4—Y. DE CARLAN, C. REGNARD, M. GRIFFITHS, D. GILBON, AND C. LEMAIGNAN 638
Discussion 652

EFFECTS OF PROCESSING ON STRUCTURES AND PROPERTIES

Effects of Extrusion-Billet Preheating on the Microstructure and Properties of Zr-2.5Nb Pressure Tube Materials—R. CHOUBEY, S. A. ALDRIDGE, J. R. THEAKER, C. D. CANN, AND C. E. COLEMAN 657

Zircaloy-2 Lined Zirconium Barrier Fuel Cladding—C. D. WILLIAMS, M. O. MARLOWE, R. B. ADAMSON, S. B. WISNER, R. A. RAND, AND J. S. ARMIJO 676
Discussion 692

Effects of Microstructure on Ductility and Fracture Resistance of Zr-1.2Sn-1Nb-0.4Fe Alloy—S. A. NIKULIN, V. I. GONCHAROV, V. A. MARKELOV, AND V. N. SHISHOV 695
Discussion 709

Influence of Processing Variables and Alloy Chemistry on the Corrosion Behavior of ZIRLO Nuclear Fuel Cladding—R. J. COMSTOCK, G. SCHOENBERGER, AND G. P. SABOL 710
Discussion 724

Effects of Thermomechanical Processing on In-Reactor Corrosion and Post-Irradiation Mechanical Properties of Zircaloy-2—P. Y. HUANG, S. T. MAHMOOD, AND R. B. ADAMSON 726
Discussion 756

Embrittlement of Reactor Core Materials—P. H. KREYNS, W. F. BOURGEOIS, C. J. WHITE, P. L. CHARPENTIER, B. F. KAMMENZIND, AND D. G. FRANKLIN 758
Discussion 782

IN-REACTOR BEHAVIOR

Zirconium Alloy E635 as a Material for Fuel Rod Cladding and Other Components of VVER and RBMK Cores—A. V. NIKULINA, V. A. MARKELOV, M. M. PEREGUD, Y. K. BIBILASHVILI, V. A. KOTREKHOV, A. F. LOSITSKY, N. V. KUZMENKO, Y. P. SHEVNIN, V. K. SHAMARDIN, G. P. KOBYLYANSKY, AND A. E. NOVOSELOV 785
Discussion 804

Corrosion Behavior of Duplex and Reference Cladding in NPP Grohnde—O. A. BESCH, S. K. YAGNIK, K. N. WOODS, C. M. EUCKEN, AND E. R. BRADLEY 805
Discussion 824

Development of New Zirconium Alloys for a BWR—Y. ETOH, S. SHIMADA, T. YASUDA, T. IKEDA, R. B. ADAMSON, J.-S. F. CHEN, Y. ISHII, AND K. TAKEI 825
Discussion 849

Comparison of the Long-Time Corrosion Behavior of Certain Zr Alloys in PWR, BWR, and Laboratory Tests—F. GARZAROLLI, Y. BROY, AND R. A. BUSCH 850
Discussion 863

In-BWR and Out-of-Pile Nodular Corrosion Behavior of Zry-2/4 Type Melts with Varying Fe, Cr, and Ni Content and Varying Process History—H. RUHMANN, R. MANZEL, H.-J. SELL, AND D. CHARQUET 865
Discussion 883

Development of Pressure Tubes with Service Life Greater Than 30 Years—C. E. COLEMAN, B. A. CHEADLE, C. D. CANN, AND J. R. THEAKER 884

Indexes 899

Overview

From its inaugural meeting in Philadelphia in 1968, the ASTM Symposium on Zirconium in the Nuclear Industry has been the premiere vehicle for discussion and documentation of the scientific and technological bases for the utilization of zirconium-based alloys in water-cooled reactors. The eleventh conference in this symposium series, held in September 1995 in Garmisch-Partenkirchen, Germany, continued this tradition of excellence. Attendees to this conference numbered 209, representing 16 countries. After careful peer review and editing, forty-one technical papers presented at this conference are published in this book. The highlights of the oral discussions have also been captured and appear at the end of each paper. This publication also includes two papers that are significant contributions to zirconium technology which served as the basis for the authors receiving the W. J. Kroll awards for 1993 and 1994. In Garmisch-Partenkirchen the awards for these years were presented to J. A. L. Robertson and to the team comprised of Friedrich Garzarolli, Heinz Stehle, and Eckard Steinberg, respectively. These Kroll Award papers represent historical as well as technical significance for the use of zirconium alloys in the nuclear industry.

Since their development in the 1950s and introduction into commercial nuclear power plants in the 1960s, the zirconium-based alloys Zircaloy-2 and -4, Zr-1Nb, and Zr-2.5Nb are the alloys currently used in the world's reactors. However, with increasing fuel duty, the margins displayed by these alloys have eroded, and considerable research has been conducted to improve these materials and also to develop more advanced alloys. Optimization of alloying constituents and processing parameters, coupled with a more basic understanding of performance-limiting phenomena, are the primary themes of most of the papers contained herein. Fully half of the papers are directly concerned with the corrosion of Zr-based alloys, and several trends are developing, which include: (1) uniform corrosion resistance is favored when oxide grains are columnar, rather than equiaxed in shape; (2) lithium-accelerated corrosion of Zircaloys corresponds to the formation of equiaxed grains in the oxide in preference to the usually occurring columnar grains; (3) in-reactor acceleration of corrosion observed in PWRs may be partially due to a lithium enhancement even at the low lithium concentrations used in PWRs, and (4) an effect due to hydrogen pickup and accumulation at the metal oxide interface may provide a significant contribution to the in-reactor acceleration of corrosion.

The detailed characterization of the effects of irradiation on the microstructure of irradiated Zircaloys has confirmed the loss of iron from second phase particles, with or without amorphization of the particles. Also, the correspondence between iron in solution in the matrix, the formation of ⟨c⟩-type dislocations, and the onset of accelerated irradiation induced growth has been verified. Unfortunately, the role of dissolved iron in the matrix in the nucleation of ⟨c⟩-type dislocations has not been established. One observation that has been verified, however, is the low irradiation growth in Zr-Nb-Sn-Fe alloys, also presumably due to suppression of ⟨c⟩ dislocation formation.

Several papers in the symposium focused on fuel clad modeling, and although a schism still exists between fundamental material properties and fuel performance predictive codes, the modeling papers presented are attempts to link component response to the quantifiable material behavior in a manner consistent with qualitative structural observations.

In summary, the data, analyses, hypotheses, and theories presented in this book represent the current state of zirconium technology as applied to nuclear power reactors. These contributions add strength to the foundation of our knowledge in this important and challenging technology.

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