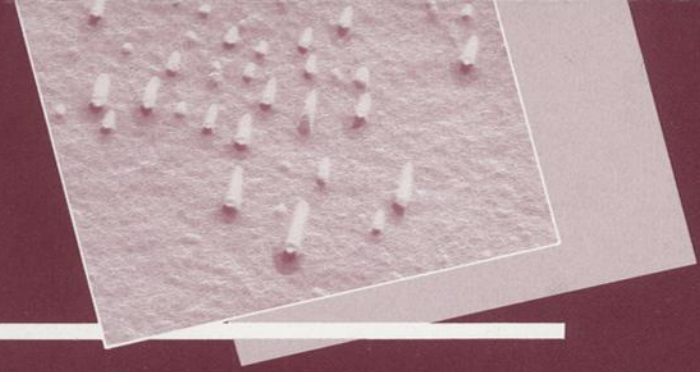
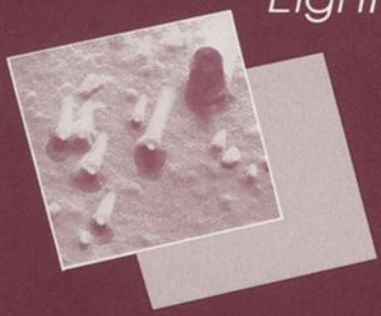


Zirconium in the Nuclear Industry

Eighth International Symposium



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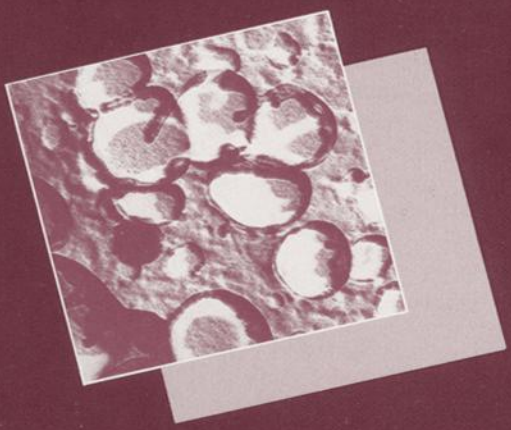

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Foreword

The Eighth International Symposium on Zirconium in the Nuclear Industry was held 19–23 June 1988 at San Diego, CA. The symposium was sponsored by ASTM Committee B-10 on Reactive and Refractory Metals in cooperation with the International Atomic Energy Agency. Leo F. P. Van Swam, Advanced Nuclear Fuels Corporation, Maxi C. Noe, International Atomic Energy Agency, and Craig M. Eucken, Teledyne Wah Chang Albany, served as chairmen of the symposium. Leo F. P. Van Swam and Craig M. Eucken are editors of the resulting publication.

Contents

CORROSION II

NODULAR CORROSION

BASIC METALLURGY

MECHANICAL BEHAVIOR, STRESS CORROSION, AND FATIGUE

CREEP AND GROWTH

Overview

This volume contains papers presented at the Eighth International Symposium on Zirconium in the Nuclear Industry held in San Diego, CA, in June 1988. Zirconium alloys have found widespread application in the core of nuclear power plants since their first use in the early 1950s. The behavior of zirconium alloys in reactor environments and in laboratory tests designed to simulate some aspect of in-reactor service conditions has been of ongoing interest since the first application of zirconium to reactor usage. The symposia were organized to provide a forum for technical discussion of zirconium alloy applications and properties. The first of these meetings was held in Philadelphia in 1968, and the published proceedings of this and subsequent conferences have become one of the most significant bodies of information on zirconium alloy behavior available in the literature. Most of the papers presented at the San Diego symposium are published here after careful peer review and editing. The most significant parts of the discussion that ensued after the oral presentation of each paper are included as well.

Previous symposia in this series have placed particular emphasis on the use of zirconium alloys, especially the Zircaloys (Zr-1.5Sn alloys with small additions of iron, chromium, and nickel), in light water reactors. A special session of this symposium was devoted to behavior of pressure tubes, especially the Zr-2.5Nb pressure tubes used in the Canadian Deuterium Uranium (CANDU) pressurized heavy water reactors.

While the Zircaloys have proven to be quite successful in their designed usage, a desire for longer lifetimes of core components and increased duty cycle puts more demand on materials performance. This demand has led to more in-depth studies of phenomena associated with zirconium alloy corrosion mechanisms, to fine tuning of the Zircaloy composition and to evaluation of new zirconium alloys. In-reactor experience formed the basis for about a third of the papers presented. New data for many of the topics covered in previous symposia are presented, including irradiation growth, stress corrosion cracking, hydriding, texture and mechanical properties, and creep and corrosion behavior. Increased emphasis on understanding the basis of the kinds of behavior observed resulted in a number of papers dealing with compositional or structural phenomena occurring on a microscopic, or even on an atomic scale.

Several presentations described the importance of iron content or distribution on corrosion resistance of Zircaloy. Bulk iron content, iron content within the matrix zirconium as measured by atom probe, and variability of iron content within 10 μm areas were reported to be related to either uniform or nodular corrosion resistance of Zircaloy. High or uniform iron content was found to be beneficial. Diffusion of iron in zirconium was reported to be extremely rapid at temperatures as low as 500°C. The solubility of iron in zirconium at 820°C was reported to be 120 ppm. Intermetallic particles of zirconium-iron-chromium were ob-

served to precipitate when Zircaloy-4 is quenched from the beta phase. The size and distribution of these Laves phase intermetallic particles is thought to influence the corrosion behavior of the Zircaloys.

Papers dealing with nodular corrosion of Zircaloy once again were a significant part of the symposium. Processing variables are known to have an impact on nodular corrosion resistance, and processes that are characterized by low-temperature deformation and annealing were reported to result in better nodular corrosion resistance than higher temperature processing. Intermetallic particle distribution has previously been reported as affecting nodular corrosion resistance, and work presented in this conference showed that the presence of large variations in the content of the intermetallic particle forming elements iron, chromium, and nickel leads to degradation of nodular corrosion resistance. Out of reactor tests to evaluate the nodular corrosion resistance of zirconium alloys have been used for several years, and a test method involving autoclave exposure of samples to steam at 520°C was proposed as a more representative test for discriminating nodular corrosion resistance than these previous tests.

The effect of annealing on the corrosion resistance of the Zircaloys was described by several authors. A specific composition within the Zircaloy-2 chemistry range was shown to be insensitive to the detrimental effect of accumulated annealing on nodular corrosion resistance. A specific range of total annealing, as expressed by an annealing parameter, was recommended for best uniform corrosion resistance of Zircaloy-4 in pressurized water reactors (PWRs) and for nodular corrosion of Zircaloy-4 in BWR's, but another author reported that the achievement of optimum uniform corrosion resistance must include not only a total annealing range but also specific parameters of the final anneal.

The proceedings also include two papers, which have historical as well as technical significance to the use zirconium alloys in the nuclear industry. The W. J. Kroll Zirconium Medal for 1986 and 1987 were presented to Dr. J. Googin and Dr. Y. Mishima, respectively. The text of the award recipients' speeches are included in this volume as the first two papers.

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