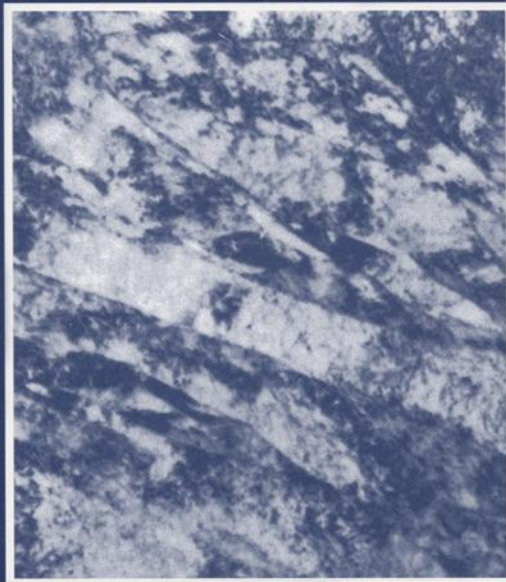
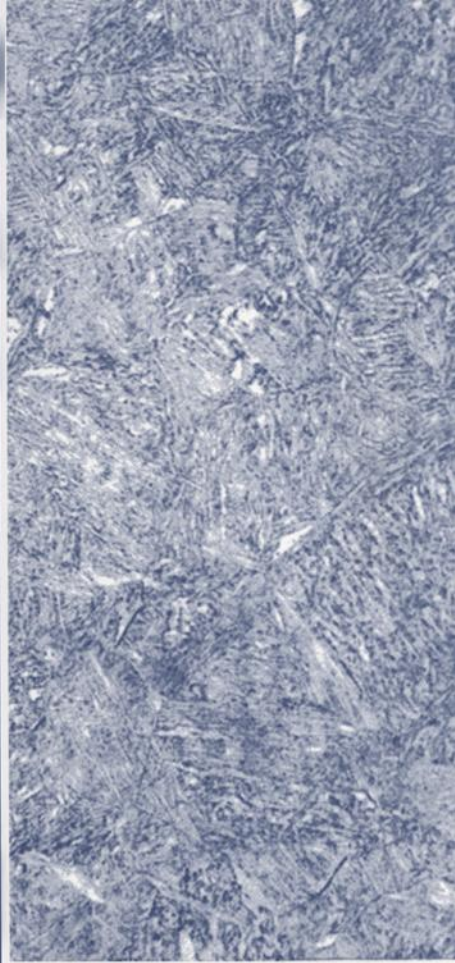


# High-Chromium Ferritic and Martensitic Steels for Nuclear Applications



Ronald L. Klueh and  
Donald R. Harries



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# Foreword

THIS PUBLICATION, *High-Chromium Ferritic and Martensitic Steels for Nuclear Applications*, was sponsored by ASTM Committee E10 on Nuclear Technology and Applications. The authors were Ronald L. Klueh and Donald R. Harries. This is Monograph 3 in ASTM's monograph series.

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# CONTENTS

|  |            |
|--|------------|
| <b>Preface</b>   | <b>vii</b> |
| <b>Chapter 1—Introduction</b>  | <b>1</b>   |
| <b>Chapter 2—Development of High (7-12%) Chromium<br/>Martensitic Steels</b>         | <b>5</b>   |
| <b>Chapter 3—Physical Metallurgy of High-Chromium Steels</b>                         | <b>28</b>  |
| <b>Chapter 4—Thermal Stability</b>   | <b>39</b>  |
| <b>Chapter 5—Oxidation, Corrosion, and Compatibility</b>                             | <b>56</b>  |
| <b>Chapter 6—Hydrogen Isotope Effects</b>  | <b>63</b>  |
| <b>Chapter 7—Joining</b>   | <b>71</b>  |
| <b>Chapter 8—Irradiation Damage, Irradiation Facilities,<br/>Irradiation Testing</b> | <b>81</b>  |
| <b>Chapter 9—Dimensional Stability—Swelling</b>                                      | <b>90</b>  |
| <b>Chapter 10—Interfacial Segregation and Precipitation<br/>During Irradiation</b>   | <b>103</b> |
| <b>Chapter 11—Irradiation Creep</b>  | <b>113</b> |
| <b>Chapter 12—Irradiation Effects on Tensile Behavior</b>                            | <b>122</b> |
| <b>Chapter 13—Elevated-Temperature Helium Embrittlement</b>                          | <b>135</b> |
| <b>Chapter 14—Irradiation Effects on Impact Properties</b>                           | <b>139</b> |
| <b>Chapter 15—Fracture Toughness</b>   | <b>167</b> |
| <b>Chapter 16—Fatigue and Fatigue Crack Growth</b>                                   | <b>177</b> |
| <b>Chapter 17—Recovery (Annealing) of Radiation Damage</b>                           | <b>205</b> |
| <b>Chapter 18—Summary: Past, Present, and Future</b>                                 | <b>208</b> |
| <b>Index</b>   | <b>217</b> |

# Preface

The high-chromium (9–12 wt%) ferritic/martensitic steels were developed during the first half of the last century and have a long history of use in the power-generation industry as boiler and turbine materials as well as for other applications. The original steels were based on 12% Cr and 9 and 12% Cr-Mo compositions, but the need for reduced generating costs in power plants (higher efficiencies, which means higher temperatures) has resulted in the development of more highly alloyed steels with progressively enhanced creep-rupture strengths. These developments have allowed the maximum operating temperatures in the boilers to be increased from less than 450 to 620°C and the  $10^5$  h creep-rupture strengths to be raised from around 40 to 140 MPa. Advanced steels of this type are now being developed with a target operating temperature of 650°C and a  $10^5$  h creep-rupture strength of 180 MPa.

High-chromium Cr-Mo steels were selected for use in steam generators of nuclear power plants during the 1960s, and steels with additions of V, Nb, and/or W and with oxide dispersions were subsequently chosen and evaluated as fuel element core component (ducts and cladding) materials in sodium-cooled fast breeder reactors. Since the late 1970s, the steels have also been considered as potential first wall and breeding blanket structural materials in fusion reactor systems. The fission (in-core) and fusion reactor applications require steels that are resistant to radiation damage induced by bombardment from high-energy neutrons as well as to retain adequate toughness and elevated-temperature strength during service. The requirement for safe and routine operation and decommissioning of a fusion plant and the disposal of radioactive wastes has also demanded the development of steels with enhanced radioactive decay characteristics. This development of “reduced-activation” steels, containing W, V, Mn, Ta, and Ti and without Mo, Nb, Ni, and other radiologically undesirable elements and possessing an appropriate combination of the other desirable properties, is still progressing.

This monograph presents a detailed review of the development of the high-chromium ferritic/martensitic steels for exposure to the high-energy neutron environment of a fission or fusion reactor, and the book should be of most interest for people involved in the use of the steels for nuclear applications. However, to provide a baseline for understanding the irradiation effects on the steels, it is first necessary to understand the basic properties of the steels under nonnuclear conditions. Therefore, many of the chapters are devoted to such considerations, and it is hoped that this information will be of interest to readers beyond those involved in nuclear applications.

## About the authors



**Dr. Ronald L. Klueh** received a B.S. degree from Purdue University and an M.S. and Ph.D. from Carnegie Mellon University. He has been conducting research on materials at the Oak Ridge National Laboratory since 1966, when he began work on compatibility and corrosion. His work on ferritic steels began in 1970, when he studied the mechanical properties of 2 1/4Cr-1Mo steel for fast reactor steam generators. Beginning in 1980, he joined the fusion materials program to study irradiation damage of ferritic/martensitic steels. He led an effort to develop reduced-activation steels for fusion applications, which resulted in a 9Cr steel with the best irradiation resistance of any such steel developed for the fusion programs worldwide. A series of 3Cr-WV bainitic steels were also developed and patented.

Since 1993, he has headed the U.S. delegation to the International Energy Agency Working Group on Ferritic/Martensitic Steel for Fusion, a committee that is coordinating an international collaboration to demonstrate the feasibility of these steels for fusion. He is a fellow of ASM International and has over 175 publications in the open literature, two patents, and has edited three books.



**Dr. Donald R. Harries** received the degrees of B.Sc. (Honors Metallurgy) from the University of Wales and a Ph.D. and Sc.D. from the University of Cambridge. He was Leader of the Core Components and Structural Materials Group, Metallurgy Division, Atomic Energy Research Establishment, Harwell, England, and subsequently Head of Technology, The NET Team, Garching, Germany, and Chief Metallurgist, British Nuclear Fuels plc, Fuel Division, Preston, U.K. He has also been a visiting scientist at the Oak Ridge National Laboratory, U.S.A., and Forschungszentrum Karlsruhe, Germany. Dr. Harries has worked as an independent metallurgical and nuclear consultant since retiring from BNFL.

He has published over 100 papers in scientific and technical journals and about 250 reports on the structure, deformation, mechanical properties, fracture behavior and irradiation effects in materials for nuclear fission and fusion power reactor systems. Dr. Harries is a member of The Institute of Materials, a Chartered Engineer and a Fellow of The Institution of Metallurgists; he is a recipient of the Charles Eichner Medal of the Société Française de Métallurgie for exceptional contributions in the field of nuclear power.