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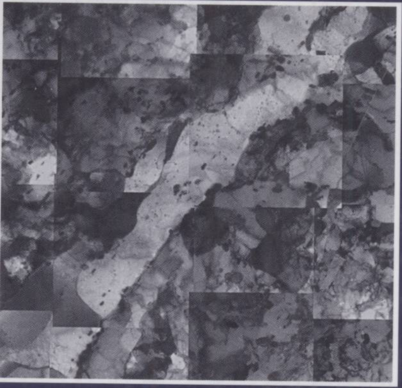

Creep-resistant steels

Edited by Fujio Abe, Torsten-Ulf Kern
and R. Viswanathan

CRC

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Preface

Creep-resistant steel that can be used for a long time at elevated temperature is the key to the construction of thermal and nuclear power generation plants, chemical plants and petroleum plants. During the last decade, great progress has been made in developing creep-resistant steels of high strength and corrosion resistance at ever increasing temperatures and in evaluating the steels in terms of the weld characteristics, creep strength and corrosion resistance necessary for constructing plants. Although in the past the driving force for these developments has been primarily to achieve higher efficiencies, the focus has shifted more recently to the reduction of emissions of CO_2, dioxins and other environmentally hazardous gases.

In the field of thermal power generation, the maximum allowable temperature was about 565°C for conventional low alloy ferritic steels. However, progress in recent years has led to the development of high-strength 9–12% Chromium ferritic steels capable of operating in ultra super critical (USC) power plants at metal temperatures approaching up to 650°C. The creep strength of austenitic creep-resistant steels has been enhanced to enable operation up to temperatures of 675–700°C through the development of high Cr, high nickel steels. In the field of nuclear power, creep-resistant steels, which are excellent both in high-temperature creep strength and in irradiation resistance, have been developed for cladding tubes for 650°C fast breeder reactors. The temperature and pressure used were 454°C and 17 MPa, respectively in the early 1990s for hydrogen refining equipment in chemical plants, when reaction chambers were made of 2.25Cr–1Mo steel, but the subsequent development of high-strength 3Cr–1Mo–V steel and 2.25Cr–1Mo–V steel raised the limiting temperature and pressure to 482°C and 24 MPa, respectively, by 1995. These figures are now about to reach 510°C and 24 MPa. For power generation from wastes, the development of austenitic creep-resistant steels that have high corrosion resistance enabled the boiler steam temperature to be raised from about 300°C in conventional plants up to about 500°C in more modern plants. In the automotive field, exhaust manifolds used to be made of cast iron to withstand exhaust heat. However, as the exhaust gas temperature rose with improved engine performance, higher strength was required and so 18Cr–2Mo–Nb and other steels were developed, raising the exhaust gas temperature to 900°C or higher.

Recent research on enhancing the creep strength of 9–12Cr steels for 650°C operation has revealed that the formation of even a partially weak microstructure near a grain boundary promotes local creep deformation and causes premature fracture. This suggests the importance of taking into account microstructural evolution phenomena during creep such as precipitation and coarsening of carbonitrides and intermetallic compounds, dynamic recovery and dynamic recrystallization, in the matrix as well as in the vicinity of grain boundaries.

Recently, some high-strength 9–12Cr steels have been found to suffer premature loss of creep strength at 550°C or higher often after prolonged use up to relevant times. Therefore, efforts have been made to clarify the mechanisms of creep strength loss, using modern transmission electron microscopy studies. Extrapolation of short duration laboratory data using time–temperature parameter (TTP) methods, such as the Larson–Miller parameter, have been used widely in the past to predict long-term life. However, it has now become clear that conventional TTP methods tend to overpredict the long term strength because of microstructural degradation phenomena. To address this issue, new analysis techniques have been proposed taking the mechanisms of creep deformation and creep rupture into account.

Welded structures made of ferritic creep-resistant steels used under high temperature and low stress (about 600°C and 100 MPa or less) are subject to premature brittle creep fracture by the so-called type IV fracture in the fine-grained heat-affected zone (HAZ). Therefore, 9–12Cr steels are being investigated to clarify the mechanisms and the means of preventing this form of fracture. Operation of thick section components under thermally cyclic conditions further exacerbates the cracking problem by creep–fatigue interaction. Thus, as plant temperatures are raised to improve energy efficiency, it is becoming increasingly important to establish the foundation of creep-resistant steels that can be used safely for a long time without showing deterioration of creep strength and creep ductility.

The aim of this book is to consolidate and review the current state of knowledge of creep resistant steels, summarizing the information which is now scattered throughout voluminous scientific journals and a large number of proceedings of international conferences. Each chapter of the book has been written for engineers and researchers in particular by a world renowned expert in the field. Therefore, the book contains not only background on materials but also recent progress from an engineering and technology point of view. It also can be used as a reference source by graduate level students. It is hoped that the book will serve as an authoritative source of information relating to creep of steels.

This book consists of three parts: a general Part I on specifications and manufacture, Part II on the behaviour of creep-resistant steels and Part III on specific applications. The introductory Part I includes the introductory description of creep and rupture (Chapter 1) and the historical development of creep-resistant steels (Chapter 2). Part I also includes the specifications of creep-resistant steels in Europe (Chapter 3) and in Japan (Chapter 4) and the production of creep-resistant steels for turbines (Chapter 5). Part II on the behaviour of creep-resistant steels covers physical and elastic behaviour (Chapter 6), diffusion behaviour (Chapter 7), fundamental aspects of creep deformation (Chapter 8), strengthening mechanisms (Chapter 9), precipitation (Chapter 10), grain boundaries (Chapter 11), fracture mechanisms and creep fracture (Chapter 12), mechanisms of creep deformation (Chapter 13), constitutive equations for creep curves and the prediction of service life (Chapter 14), creep strain analysis (Chapter 15), creep crack growth and creep-fatigue behaviour (Chapter 16), creep strength of welded joints (Chapter 17), fracture mechanics (Chapter 18), and oxidation and corrosion (Chapter 19). Part III on specific applications includes the alloy design philosophy behind creep-resistant steels (Chapter 20), creep-resistant steels in turbines (Chapter 21), creep-resistant steels in nuclear reactors (Chapter 22), and industry needs and future research trends in understanding creep damage (Chapter 23).

We are grateful to all the contributors for their willing participation and for the cooperation they have extended to us in producing this book. We are also grateful to Mr Robert Sitton, Mr Ian Borthwick, Mrs Lynsey Gathercole and Ms Laura Bunney of Woodhead Publishing for their help in the publication of this book.

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T.-U. Kern
R. Viswanathan

Contents

Part I General

Part II Behaviour of creep-resistant steels