



Creep-resistant steels

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



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Creep-resistant steels

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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 CO₂, 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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Contents

<i>Contributor contact details</i>	<i>xiii</i>
<i>Preface</i>	<i>xix</i>
Part I General	
1 Introduction	3
F. ABE, National Institute for Materials Science (NIMS), Japan	
1.1 Definition of creep	3
1.2 Creep and creep rate curves	3
1.3 Creep rupture data	7
1.4 Deformation mechanism map	9
1.5 Fracture mechanism map	11
1.6 References	14
2 The development of creep-resistant steels	15
K.-H. MAYER, ALSTOM Energie GmbH, Germany and F. MASUYAMA, Kyushu Institute of Technology, Japan	
2.1 Introduction	15
2.2 Requirements for heat-resistant steels	18
2.3 Historical development of ferritic steels	19
2.4 Historical development of austenitic steels	42
2.5 Historical development of steel melting and of the purity of heat-resistant steels	64
2.6 Summary	67
2.7 References	70
3 Specifications for creep-resistant steels: Europe	78
G. MERCKLING, RTM BREDA Milano, Italy	
3.1 Introduction	78

3.2	Specifications and standards	81
3.3	The European Creep Collaborative Committee (ECCC)	85
3.4	European Pressure Equipment Research Council (EPERC)	92
3.5	The latest generation of CEN standards for creep-resistant steels	95
3.6	Future trends	150
3.7	References	151
4	Specifications for creep-resistant steels: Japan	155
	F. MASUYAMA, Kyushu Institute of Technology, Japan	
4.1	Introduction	155
4.2	Types of heat-resistant steels in Japan	155
4.3	Specifications for high temperature tubing and piping steels	158
4.4	Specifications for steam turbine steels	169
4.5	Heat-resistant super alloys	169
4.6	Summary	169
4.7	References	173
5	Production of creep-resistant steels for turbines	174
	Y. TANAKA, Japan Steel Works, Japan	
5.1	Introduction	174
5.2	Overview of production technology of rotor shaft forgings for high temperature steam turbines	175
5.3	Production and properties of turbine rotor forgings for high temperature applications	192
5.4	Future trends	207
5.5	References	212
 Part II Behaviour of creep-resistant steels		
6	Physical and elastic behaviour of creep-resistant steels	217
	Y. YIN and R.G. FAULKNER, Loughborough University, UK	
6.1	Introduction	217
6.2	Elastic behaviour	219
6.3	Thermal properties of creep-resistant steels	225
6.4	Electrical resistivity and conductivity of creep-resistant steels	234
6.5	Implications for industries using creep-resistant steels	238
6.6	Future trends	239
6.7	References	239

7	Diffusion behaviour of creep-resistant steels	241
	H. OIKAWA and Y. IJIMA, Tohoku University, Japan	
7.1	Introduction	241
7.2	Diffusion and creep	241
7.3	Diffusion characteristics	243
7.4	Roles of atom/vacancy movement in creep	248
7.5	Influence of some factors on creep through their effects on diffusion	250
7.6	Diffusion data in iron and in some iron-base alloys	255
7.7	Concluding remarks	260
7.8	References	263
8	Fundamental aspects of creep deformation and deformation mechanism map	265
	K. MARUYAMA, Tohoku University, Japan	
8.1	Introduction	265
8.2	Stress–strain response of materials	265
8.3	Temperature and strain rate dependence of yield stress	267
8.4	Deformation upon loading of creep test	269
8.5	Creep behavior below and above athermal yield stress	270
8.6	Change in creep behavior at athermal yield stress σ_a	271
8.7	Deformation mechanism maps	275
8.8	Concluding remarks	278
8.9	References	278
9	Strengthening mechanisms in steel for creep and creep rupture	279
	F. ABE, National Institute for Material Science (NIMS), Japan	
9.1	Introduction	279
9.2	Basic ways of strengthening steels at elevated temperature	279
9.3	Strengthening mechanisms in modern creep-resistant steels	287
9.4	Loss of strengthening mechanisms in 9–12Cr steels during long time periods	295
9.5	Future trends	301
9.6	References	301
10	Precipitation during heat treatment and service: characterization, simulation and strength contribution	305
	E. KOZESCHNIK and I. HOLZER, Graz University of Technology, Austria	
10.1	Introduction	305

10.2	Microstructure analysis of the COST alloy CB8	306
10.3	Modelling precipitation in complex systems	312
10.4	Computer simulation of the precipitate evolution in CB8	315
10.5	Microstructure–property relationships	320
10.6	The back-stress concept	322
10.7	Loss of precipitation strengthening during service of CB8	324
10.8	Summary and outlook	325
10.9	References	326
11	Grain boundaries in creep-resistant steels	329
	R.G. FAULKNER, Loughborough University, UK	
11.1	Introduction	329
11.2	Ferritic steels	330
11.3	Austenitic steels	341
11.4	Grain boundary properties and constitutive creep design equations	345
11.5	Future trends	346
11.6	References	347
12	Fracture mechanism map and fundamental aspects of creep fracture	350
	K. MARUYAMA, Tohoku University, Japan	
12.1	Introduction	350
12.2	Fracture mechanisms and ductility of materials	351
12.3	Stress and temperature dependence of rupture life	352
12.4	Fracture mechanism maps	355
12.5	Influence of fracture mechanism change on creep rupture strength	356
12.6	Influence of microstructural degradation on creep rupture strength	358
12.7	Change in creep rupture properties at athermal yield stress	359
12.8	Multi-region analysis of creep rupture data	361
12.9	Summary	362
12.10	References	364
13	Mechanisms of creep deformation in steel	365
	W. BLUM, University of Erlangen-Nuernberg, Germany	
13.1	Introduction	365
13.2	Initial microstructure	366
13.3	Creep at constant stress	368
13.4	Transient response to stress changes	370