

Table of content

1. Introduction.....	1
2. State of the art	5
2.1. Applications	5
2.2. 9-12% Cr steels	6
2.3. Metallurgy	7
2.4. Precipitates	11
2.5. Creep fundamentals	17
2.6. Strengthening mechanisms	22
3. Materials and methods	24
3.1. Materials.....	24
3.2. Heat-treatment.....	25
3.3. Creep testing.....	26
3.4. Optical metallography and hardness	27
3.5. Scanning electron microscopy	27
3.6. Transmission electron microscopy	30
4. Results	34
4.1. Creep data	34
4.2. Creep cavities and inclusions	36
4.3. Evolution of hardness	40
4.4. Evolution of subgrain	41
4.5. Evolution of misorientation	44
4.6. Evolution of dislocations density	49
4.7. Identification of precipitates	53
4.8. Evolution of precipitate parameters.....	57
4.9. Chemical evolution of precipitates	62
5. Discussion.....	65
5.1. Creep data	65
5.2. Creep cavities and inclusions	65
5.3. Evolution of hardness	65
5.4. Evolution of subgrain	66
5.5. Evolution of low angle boundaries	70
5.6. Evolution of dislocation density.....	70
5.7. Stability of precipitates	71
5.8. Chemical evolution of precipitates	74
5.9. Laves phase nucleation and growth	75
6. Conclusions.....	84

List of Figures

Figure 1-1: Heat rate of steam power plants in Germany as a function of steam parameters. 1	
Figure 1-2: International research and development projects on steam power plants [17]. ... 2	
Figure 2-1: Schematic illustration and photographs of a fossil fired boiler and their typical materials..... 5	
Figure 2-2: Schematic illustration of microstructure of tempered martensite 9-12%Cr creep-resistant steel contains precipitates on the internal interfaces. 7	
Figure 2-3: Schematic of crystal structure of Cr_{23}C_6 carbide with fcc structure. 11	
Figure 2-4: Schematic of crystal structure of VC carbide with fcc structure. 13	
Figure 2-5: Schematic of crystal structure of Fe_2W carbide with hcp structure..... 13	
Figure 2-6: Schematic of Ostwald ripening mechanism in which larger particles grow up while small particles dissolving into matrix. 15	
Figure 2-7: Creep curve of an engineering steel under constant tensile load and constant temperature. 17	
Figure 3-1: Schematic of the position and direction of creep specimens taken from X20CrMoV12-1 pipe. 24	
Figure 3-2: Continuous cooling transformation (CCT) diagram of X20CrMoV12-1 steel. 25	
Figure 3-3: a) As-received specimen taken from a pipe, b) creep ruptured specimen after 139971 hours at 823 K under 120 MPa..... 26	
Figure 3-4: Schematic of EBSD technique. 28	
Figure 3-5: Diagram of the bright-field, annular dark-field, and high-angle annular dark-field functions of a STEM..... 30	
Figure 3-6: Procedure to identify and evaluate the precipitates in HAADF—STEM images. .. 32	
Figure 3-7: Schematic figure illustrating the parameters which were retrieved from the TEM micrographs: particle size, number density and projected area fraction..... 33	
Figure 4-1: Diagram of strain vs. logarithm of time of specimens with 0.5, 1.0, and 1.6% strain and ruptured specimen. 35	
Figure 4-2: Logarithm of creep rate vs. logarithm of time at 823 K for specimens 0.5, 1.0, 1.6 and 11.9% strain..... 35	
Figure 4-3: logarithm of creep rate vs. strain for the ruptured specimen at 823 K and 120 MPa after 139971 hours. 36	