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DEVELOPMENT OF MICROSTRUCTURE OF STEEL FOR THERMAL POWER GENERATION

RAZVOJ MIKROSTRUKTURE JEKEL ZA TERMIČNO GENERACIJO ENERGIJE

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The evolution of microstructure during the reheating and cooling of steel for thermal power generation was investigated. On the basis of the microstructure produced during cooling a CCT diagram is proposed.

Key words: steel, thermal power generation, microstructure, CCT diagram

Raziskan je bil razvoj mikrostrukture pri segrevanju in ohlajanju jekel za toplotno generacijo energije. Na podlagi mikrostrukture, ki je nastala pri ohlajanju, je bil predložen CCT-diagram.

Ključne besede: jeklo, toplotna generacija energije, mikrostrukture, CCT diagram

1 INTRODUCTION

Natural gas is now an important source of energy. However, especially in developing countries, lignite and anthracite will also be used for the generation of electrical energy, and power stations utilizing these energy resources for steam production will also play an important role in the future.

The minimization of the capital costs required to build new steam-power stations leads to the extensive use of ferrite-martensite steels, or martensite steels for all the main components in boilers and turbines [1].

For modern power stations the operating conditions are defined as follows:

- 540 °C/18 MPa
- 600 °C /30 MPa
- 720 °C /37.5 MPa - expected for the future

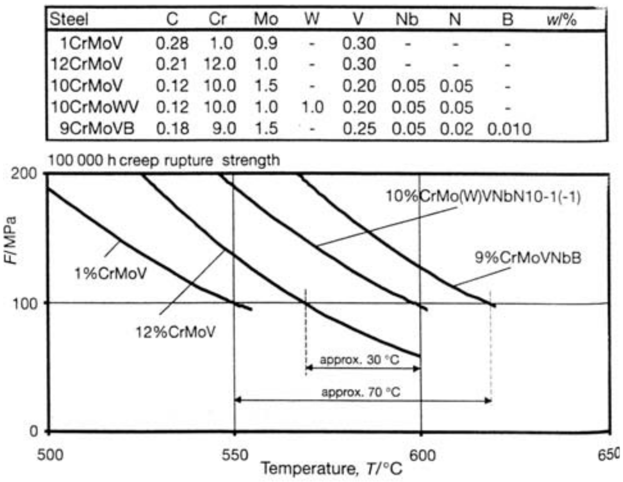
The applied materials were analyzed for their creep rupture strength under the following conditions:

- short-term creep behavior up to t = 10 000 h
- long-term creep test up to t = 100 000 h

In **Figure 1**[2] the chemical analysis and the creep resistance is given for some classic and newly developed steels.

The 1CrMoV steel has been used for a very long time and is considered as a classic steel. The steels with an increased content of Cr up to 9–12 % with addition of Nb and B are considered as newly developed types.

The newly developed steels can be, in comparison to classic materials, applied in operating conditions with increased steam temperatures of 30-70 °C. The steels for



Steel	C	Cr	Mo	W	V	Nb	N	B	w/%
1CrMoV	0.28	1.0	0.9	-	0.30	-	-	-	
12CrMoV	0.21	12.0	1.0	-	0.30	-	-	-	
10CrMoV	0.12	10.0	1.5	-	0.20	0.05	0.05	-	
10CrMoWV	0.12	10.0	1.0	1.0	0.20	0.05	0.05	-	
9CrMoVB	0.18	9.0	1.5	-	0.25	0.05	0.02	0.010	

Figure 1[2]: Creep rupture strength of the new 9–10 % Cr rotor materials applied in Europe

Slika 1: Odpornost proti lezenju pri novih 9–10 % Cr jeklih, ki se uporabljajo v Evropi

Table 1[3]: Chemical composition and properties of two steels

Tabela 1[3]: Kemična sestava in lastnosti dveh jekel

w	C	Cr	Mo	W	Ni	V	Nb	N	B/ µg/g	$R_{p0.2}$/ MPa	$FATT_{50}$/ °C
GX12CrMoVNbN9 1	0,12	9	1,0	–	0,4	0,2	0,06	0,05	80	633	+46
GX12CrMoWVNbN 10 1 1	0,12	10	1,0	1,0	0,7	0,2	0,06	0,05	10	730	+40

steam-turbine rotors can be divided into three groups according to their chemical composition:

- 10 % Cr + Mo
- 10 % Cr + W+ Mo
- 9 % Cr + Mo + B

These steels are used for the manufacturing of rotors with diameters up to 1200 mm. The basic properties for two steel grades are given in **Table 1** [3].

Besides the steels based on CrMoV or CrMoVW, steels based on CrMoNiV or CrMoNiVW have also been developed. The research work is currently oriented to improve steel technology with the aim to decrease the content of unwanted elements in the steel and to master the forging technology and heat-treating processes of these high-purity steels. The aim is to obtain good chemical and structural homogenity of the material, as well as forgings with minimum of defects [4].

The properties of steel depend on the steam characteristics, since the turbines can operate in conditions of:

- HP – high pressure
- IP – intermediate pressure
- LP – low pressure

The specifications of the material should be defined by the following characteristics:

1. Static strength – failure strength
2. Creep rupture strength, high-temperature strength
3. Toughness – fracture toughness
4. Fatigue properties – low-cycle fatigue
   – high-cycle fatigue
5. Crack growth rate – static-creep (CG)
   – alternative – fatigue
6. Corrosion resistance – local corrosion
   – corrosion under pressure
   – corrosion fatigue
7. Erosion resistance

2 MATERIAL AND EXPERIMENTS

For the experiments the CrNiMoV steel, which is the equivalent to STN 41 6537, with the chemical composition in **Table 2**, was used.

The experiments were aimed at:

- the evaluation of the influence of temperature and time on the austenite grain size.
- the influence of cooling rate on the formation of the microstructure and the ARA diagram.

The experimental methods were:

- light microscopy
- differential dilatometry

3 RESULTS AND DISCUSSION

The diagrams showing the influence of reheating temperature and reheating time on the austenite grain size change are in **Figure 2** and **Figure 3**. From the dependencies in these two figures it was concluded that:

- the holding time at 1000 °C does not influence the austenite grain size. Thus it is possible to classify this temperature as "low-sensitive" to austenite grain size change.
- the reheating temperature of 1050 °C had a great influence on the austenite grain size, while, for holding times of 15 min and 30 min the difference in the austenite grain size is on average 8 µm, but for holding times of 45 min and 60 min this difference increases on average to 45,5 µm. It is possible to classify this temperature as sensitive to austenite grain size change.
- for reheating temperatures of (1100, 1150, 1200) °C, there is a slow increase in the austenite grain size for all the reheating times. It is possible to classify this

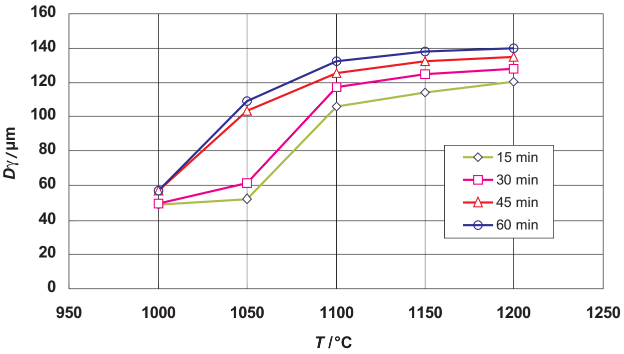


Figure 2: Dependence of AGS on reheating time
Slika 2: Odvisnost velikosti AGS avstenitnih zrn od temperature segrevanja

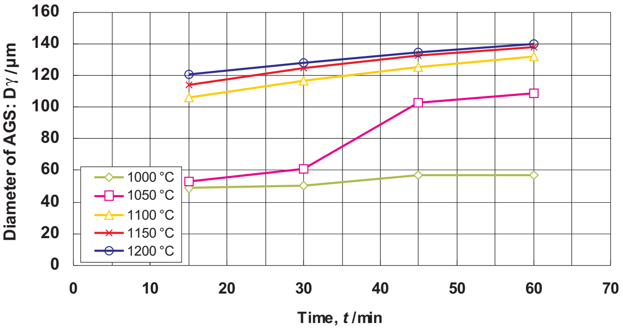


Figure 3: Dependence of AGS on reheating time
Slika 3: Odvisnost AGS od trajanja segrevanja

Table 2: Chemical analysis of the experimental steel
Tabela 2: Kemična sestava jekla za raziskavo

C	Mn	Si	P	S	Cr	Ni	Cu	Mo	V	Al	As	Sn	Sb	Ca	H	N	O
w/%											*w*/(µg/g)						
0.29	0.04	<0.01	0.003	0.003	1.57	2.84	0.010	0.39	0.11	0.004	11	8	<5	20	0.5	44	25

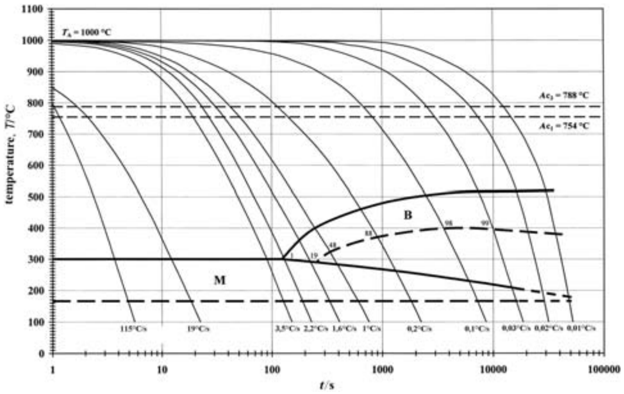


Figure 4: CCT diagram
Slika 4: CCT diagram

temperature interval as low-sensitive to austenite grain size change.

At the reheating temperature of 1050 °C a faster growth of austenite grain size is observed by increasing the reheating time. From 30 min to 45 min there is a loss of the hindering effect of carbide and nitride particles on the migration of austenite grain boundaries.

The solubility of the VC and VN precipitates for given contents of vanadium and carbon is calculated from Equations (1) and (2):

$$\lg (w(\mathrm{V})^{4/3} \cdot w(\mathrm{C})) = 7{,}06 - 10\,800/T \qquad (1)$$

$$\lg (w(\mathrm{V}) \cdot w(\mathrm{N})) = 3{,}02 - 7\,840/T \qquad (2)$$

The solubility is reached at 940 °C for vanadium carbide and 970 °C for vanadium nitride.

It is clear that the precipitates of vanadium carbide and nitride do not hinder the growth of austenite grains during the reheating time at 1050 °C.

The influence of cooling rate on the formation of the final microstructures can be evaluated by considering the dilatometry curves, the hardness and the microstructures after different cooling rates from a constant reheating temperature. In this way the transformation CCT diagram can be obtained **Figure 4**.

The obtained diagram shows that in the examined steel a real-time ferritic transformation of austenite does not occur and that only the formation of martensite, martensite + bainite, or bainite takes place. The investigated steel is thus a high-through-hardening steel.

4 CONCLUSION

From the results of the experimental work on a CrNiMoV steel it is possible to draw the following conclusions:

- for the reheating temperature T = 1000 °C, the effect of reheating time is negligible and the austenite grain size remains in the interval δ = 49–57 μm. This reheating temperature ensures the fine-grained austenitic structure, which is a good starting point for achieving a fine-grained secondary structure, also in cases without plastic deformation after reheating. This is also valid for 15 min or 30 min reheating at 1050 °C when the diameter δ = 52–61 μm is obtained.
- for the reheating temperature of 1050 °C and reheating time t = 45 min and 60 min an increased sensitivity to austenite grain growth is found and the size of δ = 103–109 μm is obtained. Similar characteristics are also observed for the reheating conditions T = 1100–1200 °C and t = 15 min or 60 min when the size of δ = 106–140 μm is obtained. If the reheating conditions are chosen considering the mentioned intervals, a controlled forging and controlled cooling regime will be required for achieving a fine-grained secondary structure.
- the CCT diagram obtained shows that the investigated steel is self-hardening.

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