INFLUENCE OF AUSTENITIZING TEMPERATURE ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF 9CrNB STEEL

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Abstract

This paper deals with the analysis of microstructure and mechanical properties of 9 Cr steel after austenitizing at temperatures of 1150 °C, 1180 °C and 1210 °C/2 hrs and after tempering at temperature of 790 °C/1 hr. Microstructure after austenitizing and quenching was formed of lath martensite and uniformly distributed ferritic area. At temperature of austenitizing of 1150 °C microstructures were relatively homogeneous. At higher austenitizing temperature of 1180 °C and 1210 °C microstructure was significantly heterogeneous. With increasing austenitizing temperature there was a significant increase of the original austenite grain boundaries. After tempering was microstructure formed by tempered martensite, with lath morphology. The results of mechanical properties ($Rp_{0.2}$, R_m, HBW, KV_2) are in good agreement with requirements for grade P91 and P92 according to the relevant norm of STN EN 10216-2+A2. The minimum values of ductility A_5 accordance with that norms were not achieved, where values were lower about 1.1 - 2.1 % compared with the prescribed value of ductility for grade P92 (min.19 %).

Keywords: Creep resistance steel, kinetics of grain growth in austenite, austenitizing temperature, tempering temperature, low carbon 9Cr steel

1. INTRODUCTION

Creep resistance martensitic steels currently have an important place in the material solution of high-exposed part of the pressure systems of power units. They replace austenitic steels on the output stage of reheaters. One of them are low carbon 9 Cr steels that are alloyed with Cr, W, Co and an optimal ratio of B and N. In comparison with grade with similar chemical composition (P91, P92), where the austenitizing temperature is about 1060 °C, at 9CrNB steels requires higher austenitizing temperatures about 100 - 150 °C, as is clear from our experiments described in the reports [1, 2]. Subsequently, these steels must be tempered at 790 °C. The main objective of this work is to develop the grade of hot rolled tubes from 9CrNB steel which is designed for ultra-supercritical conditions of stress, to achieve the desired mechanical properties. These characteristics prescribed by the standard STN EN 10216-2+A2 for grade with similar chemical composition (P91 and P92) are listed in **Table 1** [3 - 11].

Table 1 Mechanical properties according to the standard: STN EN 10216-2+A2

Grade	$YS_{0.2}$-min [MPa]	TS [MPa]	El.5 [%]	CV +20°C min [J]	HBW max
X10CrMoVNb9-1 (P91)	450	630-830	19	27	250
X10CrWMoVNb9-2 (P92)	440	620-850	19	27	250

2. MATERIAL AND EXPERIMENTAL METHODS

Hot rolled tube made of 9CrNB steel was used as an experimental material (**Table 2**). The hot rolled tube was cut into pieces of about 30 cm and subsequently austenitized at three different temperatures (1150 °C, 1180 °C and 1210 °C) with holding time of 2 hrs and cooling on the air. After austenitization hot rolled tubes were tempered at 790 °C with holding 1 hr and cooling on the air. After austenitization and also after austenitization and tempering realized microstructure was analysis on a light microscope OLYMPUS GX51. The mechanical properties ($YS_{0.2}$, TS, $El._5$, HBW, CV_2) were also measured.

Table 2 Chemical composition of 9CrNB steel

Elements	C	Mn	Si	P	S	Cr	Ni	Mo	W	Co	B	N
Min [wt. %]	0.06	0.40	0.20	-	-	8.00	-	-	2.50	2.80	0.010	0.005
Max [wt. %]	0.10	0.50	0.35	0.020	0.008	9.00	0.15	0.10	3.00	3.20	0.015	0.015

3. RESULTS

The microstructure was analyzed after austenitisation at all three austenitisation temperatures and after tempering. After austenitization microstruture was formed of lath martensite with uniform distributed ferritic area (**Figure 1, 2**). At high magnification (1000x) in microstructure secondary particles were observed, that were also present at the former austenite grain boundaries. In terms of size of the original austenite grain it can be concluded that the microstructure at austenitizing temperature of 1150 °C was relatively homogeneous. Austenite grain size was in the range of about 100 - 160 μm, while the measured mean size of the original austenitic grain was 129.3 μm. At the higher austenitizing temperature (1180 °C) in terms of the size of the original austenite grain can be concluded that the microstructure was heterogeneous. Austenite grain size was in the range of about 170 - 470 μm, while the measured mean size of the original austenitic grain was 272.5 μm. At the highest austenitizing temperature of 1210 °C significant heterogeneity of the size of austenitic grain was observed, while austenite grain size was in the range of about 260 - 620 μm. The measured mean size of the original austenitic grain was 390.5 μm.

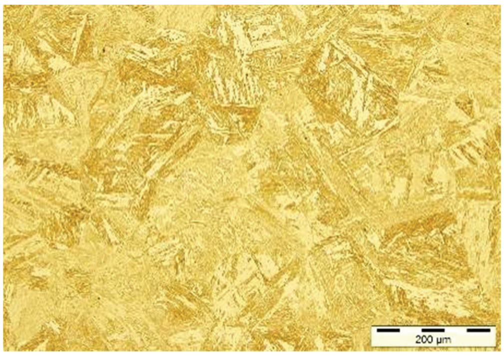

Figure 1 Microstructure after austenitizing at 1150 °C

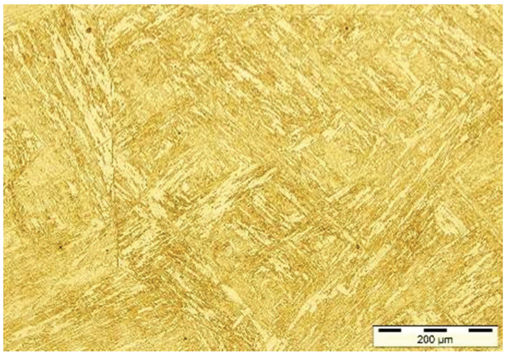

Figure 2 Microstructure after austenitizing at 1210 °C

Microstructure after austenitizing and tempering was formed by tempered martensite with lath morphology. At larger magnifications are visible in lath morphology lighter and darker areas. This is due to redistribution of inhomogeneous particle of precipitates. On the borders of tempered martensite laths were located fine particles of precipitates (**Figure 3, 4**). These particles are probably of complex particles of carbide and to their exclusion occurred during tempering also the original austenite grain boundaries. These boundaries were highlighted due to excluded particles. With increasing of austenitizing temperature there was an increase of martensite laths size.

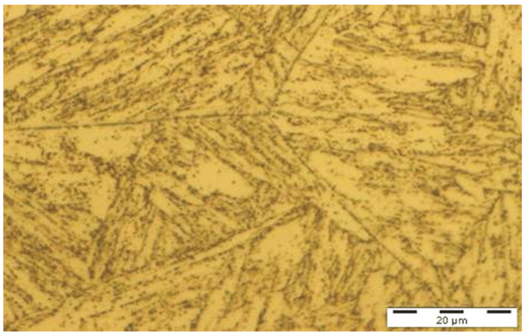

Figure 3 The fine particles of precipitates (austenitizing at 1150 °C, tempered at 790 °C)

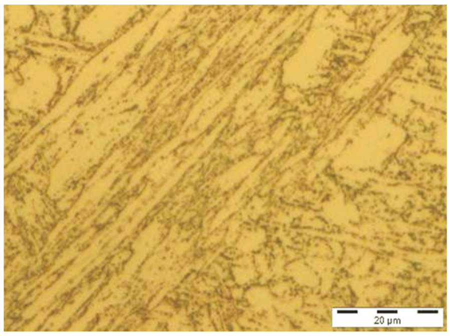

Figure 4 The fine particles of precipitates (austenitizing at 1210 °C, tempered at 790 °C)

The results of the mechanical properties after static tensile test after austenitization (A) and austenitization and tempering (T) are shown in **Table 3**. The average values were calculated for the three samples for each condition. With increasing of austenitizing temperature from 1150 °C to 1180 °C strength properties $YS_{0.2}$ and TS decreases slightly (from 932 to 907 MPa, eventually from 1261 to 1208 MPa). At the austenitization temperature of 1210 °C strength properties slightly increased. Ductility with increasing austenitizing temperature decreases (from 10.8 % to 5.4 %). Hardness reached values about 390 - 400 HBW. High values of strength properties, hardness and low ductility correspond to the condition of microstructure after hardening.

Table 3 The average values obtained mechanical properties in a condition after austenitizing and after austenitizing and tempering

Heat treatment	$YS_{0.2}$ [MPa]	TS [MPa]	$El_{.5}$ [%]	HBW	CV_2 [J]
A 1150 °C	932	1261	10.8	390.8	-
A 1180 °C	907	1208	7.1	401.4	-
A 1210 °C	919	1226	5.4	399.2	-
A 1150 °C T 790 °C	612	733	17.2	243.8	101.3
A 1180 °C T 790 °C	608	718	17.9	242.4	117.6
A 1210 °C T 790 °C	605	721	16.9	245.0	89.9

The mechanical values properties after austenitization and tempering are processed graphically (**Figures 5 - 9**) and are compared with the values according to the norm STN EN 10216-2+A2 for grade P92. Values of yield strength $YS_{0.2}$ reached 605 - 612 MPa, which represents a large reserve (about 160 - 170 MPa) at the minimum required value 440 MPa (**Figure 5**).

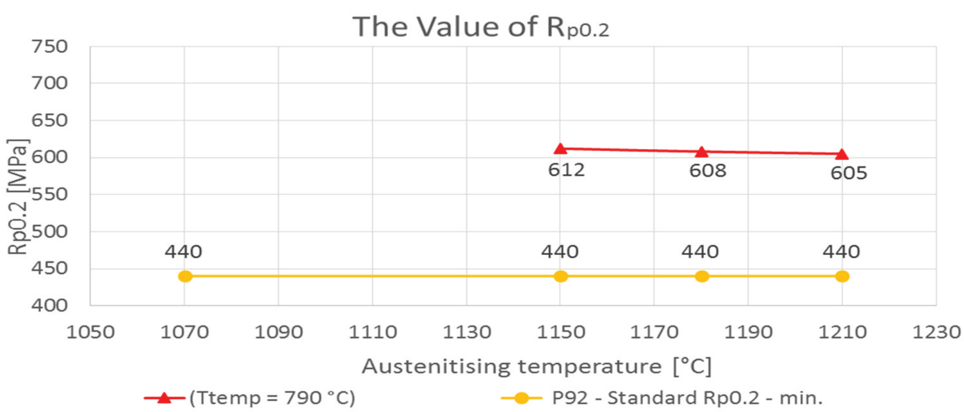

Figure 5 The values of $R_{p0.2}$ (corresponds to $YS_{0.2}$) for 9CrNB steel after austenitisation and tempering

In case of the ultimate strength TS values reached 718 to 733 MPa, which represents a reserve about 100 - 110 MPa, at the minimum required value of 620 MPa (**Figure 6**).

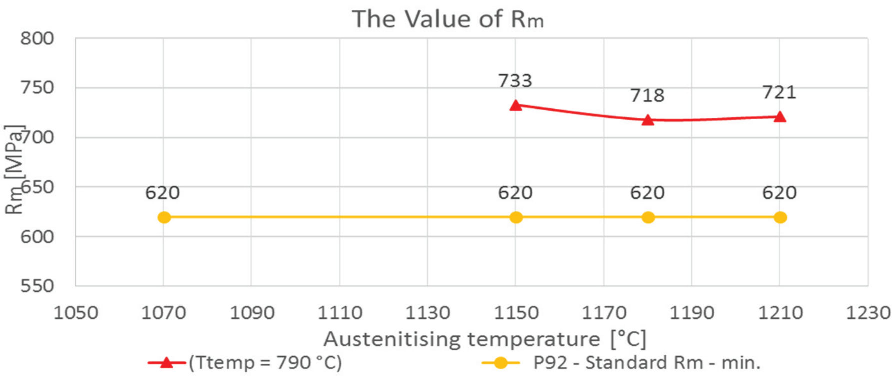

Figure 6 The values of Rm (corresponds to TS) for 9CrNB steel after austenitisation and tempering

Ductility was ranged from 16.9 to 17.9 %, which are values slightly below the prescribed minimum value of 19 % (**Figure 7**).

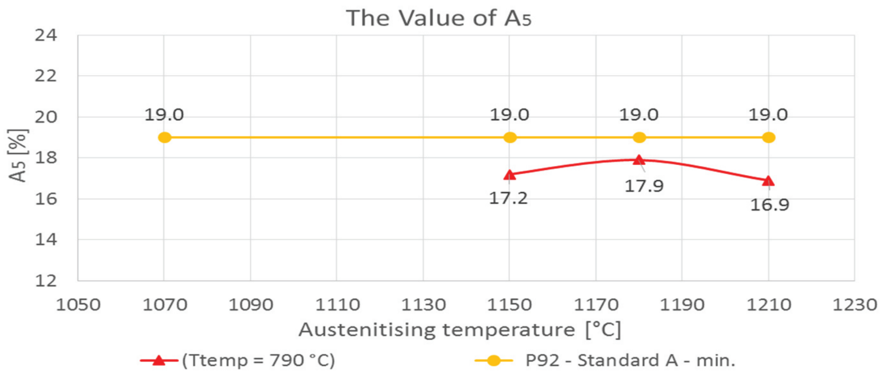

Figure 7 The values of A_5 (corresponds to El.5) for 9CrNB steel after austenitisation and tempering

The hardness values are in the range of about 242 - 245 HBW and they are slightly below the prescribed maximum value of 250 HBW (**Figure 8**).

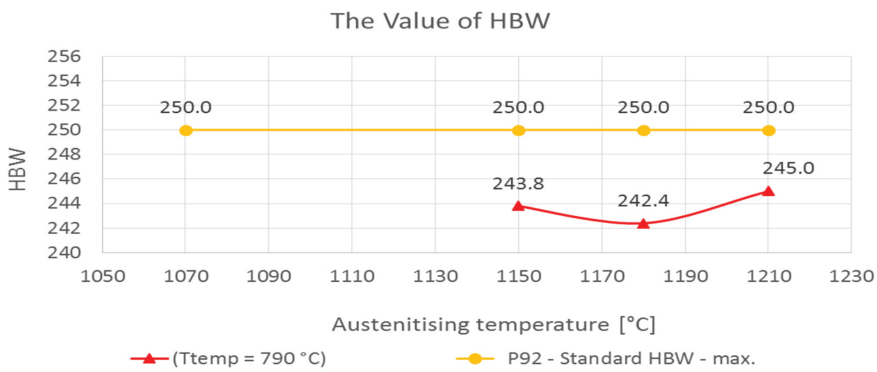

Figure 8 Values of HBW for 9CrNB steel after austenitisation and tempering

Impact toughness KV_2 was ranges from about 90 - 117 J, which represents a considerable reserve compared to the minimum required of value 27 J (**Figure 9**).

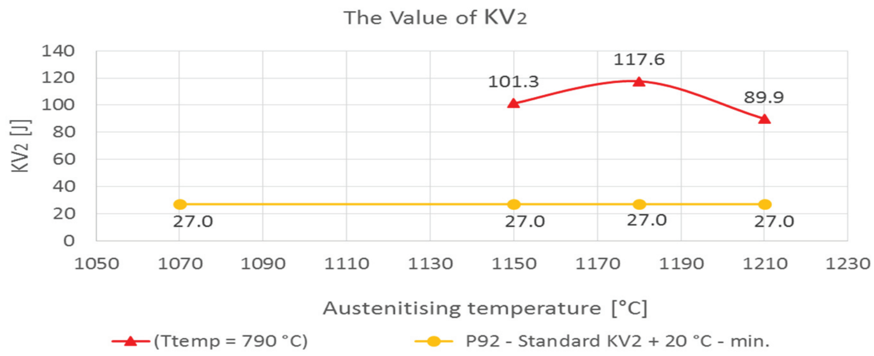

Figure 9 Values of KV_2 (corresponds to CV2) for 9CrNB steel after austenitisation and tempering

4. DISCUSSION

The microstructure of 9CrNB steel was created after austenitizing at high temperatures (1150 °C, 1180 °C, 1210 °C) by lath martensite with uniform distributed ferritic area. The microstructure corresponds to the condition after quenching. At the austenitizing temperature of 1150 °C the microstructure was relatively homogeneous with mean size of the original austenite grain 129.3 µm. At higher austenitizing temperatures (1180 °C and 1210 °C) the microstructure was significantly heterogeneous and there was an increase of medium size of austenitic grain. At austenitizing temperature of 1180 °C measured grain size was of 272.5 µm and at austenitizing temperature of 1210 °C grain size was 390.5 µm. The high degree of heterogeneity of austenite grain at higher austenitizing temperatures can influence stability of the mechanical properties, but also the degradation processes that can be implemented to the boundaries of the large austenite grains. After austenitizing subsequent tempering at 790 °C microstructure was formed by tempered martensite with lath morphology. The strength properties after austenitisation reached a high values ($YS_{0.2}$ = 907 - 932 MPa, TS = 1208 - 1261 MPa), ductility was low (5.4 - 10.8 %). Exclusion of fine carbide and carbonitride particles at the martensite laths boundaries and blocks after tempering was observed. Microstructural changes after tempering are caused by healing of substructures. These substructures exhibit healed ferritic sub-grains with decreased dislocation density [7]. After tempering, all strength properties (TS, $YS_{0.2,}$ HBW) and also toughness were fulfilled in comparison with the grade P92 according to standard STN EN 10216-2+A2. The values of tensile strength TS and yield strength $YS_{0.2}$ were fulfilled with a large safety margin compared to minimum value of 440 MPa. The hardness was slightly below the prescribed maximum value of 250 HBW. Impact toughness KV_2 was also fulfilled by a large reserve. The high values of strength properties were reflected on the ductility A_5. Values were lower by 1.1 - 2.1 % in comparison with the prescribed value of ductility for grade P92 (min.19 %). This testifies to the high intensity of hardening of secondary phases.

5. CONCLUSION

From the results of influence of austenitizing temperature on microstructure and mechanical properties of 9CrNB creep resistant steel followed these conclusions:

- Microstructure of 9CrNB steel after austenitizing was formed by lath martensite with uniform distributed ferritic area, i.e. response after quenching. At the austenitizing temperature of 1150 °C microstructure was in terms of size original austenite grain relatively homogeneous with a mean grain size of 129.3 µm. At the higher austenitizing temperature (1180 °C and 1210 °C) is the microstructure significantly heterogeneous, and the mean size of the original austenite grain was 272.5 µm, respectively 390.5 µm.
- After austenitizing and subsequent tempering at 790 °C microstructure was formed by tempered martensite with lath morphology. At the lath borders and also on martensitic blocks of fine carbide resp.

carbonitride particles were excluded. With increasing of austenitizing temperature there was an increase of martensite laths size.

- The decisive factor for achievement of the required mechanical properties $YS_{0.2}$, TS, El_5, CV_2, HBW is a high austenitizing temperature of 1170 °C ± 20 °C. The results of the experiment in this work it clearly confirmed. It was confirmed optimum of tempering temperature of 790 °C / 4 hrs. Selected austenitizing temperature enables dissolution of carbide phases after hot rolling process and their effective creation, precipitation during cooling from the austenitizing temperature. Tempering fulfilled expected effects, the strength values $YS_{0.2}$, TS and hardness HBW, but also impact toughness CV_2 fully met the requirements of standard EN 10216-2 + A2. On the other side, requirements for ductility A_5 of min.19 % (by 1.1 - 2.1 % lower) were not fulfilled. This indicates a high intensity of hardening of secondary phases. In further research it will be necessary to explain the effect of carbide phases for strengthening.

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