Influence of partitioning on mechanical properties and retained austenite stability of martensitic stainless steels

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The effect of retained austenite on the mechanical properties of martensitic stainless steels was investigated. Not only the amount of retained austenite is important, but also its stability. Different retained austenite contents were achieved by quenching and partitioning. Tensile tests were performed to obtain elongation and strength values as well as to determine the k_P-value, which describes the retained austenite stability. The investigations were carried out on two martensitic stainless steels (X40Cr14 and "X25CrN13") in order to examine also the influence of nitrogen. The results show that increasing quenching temperatures increase the retained austenite content until a maximum is reached. With increasing quenching temperature, the k_P-value also increases, and retained austenite stability decreases. For both steels the k_P-value was lowered at the higher partitioning temperature, meaning that the retained austenite was more stable, despite a higher retained austenite content. The nitrogen alloyed "X25CrN13" had similar retained austenite stability as X40Cr14 at the higher partitioning temperature, but retained austenite of X40Cr14 was more stable at the lower partitioning temperature. In general, a reduced retained austenite stability and the corresponding Transformation Induced Plasticity effect led to reduced yield and increased tensile strength as well as increased ductility. Only at highest quenching temperature, due to fresh martensite formation, ductility was reduced.

Keywords: *martensitic stainless steels, quenching and partitioning, mechanical properties, retained austenite*

1. Introduction

The typical heat treatment of martensitic stainless steels is quenching and subsequent tempering (Q&T) at different temperatures. [1] A similar heat treatment procedure is quenching and partitioning (Q&P). With Q&P, a specific retained austenite (RA) content is stabilized to achieve a favorably combination of strength and ductility due to the so-called transformation-induced plasticity (TRIP) effect. [2, 3] The difference from typical Q&T is that with Q&P the quenching temperature is always above the martensite finish temperature (M_f). During holding at tempering (=partitioning) temperature, carbon diffuses from the martensite into the retained austenite, stabilizing it. As the quenching temperature (T_q) for Q&T of martensitic stainless steels usually fulfils the criteria of a Q&P-treatment ($T_q > M_f$), subsequent partitioning effects during tempering take place, affecting the properties. [4]

The application of Q&P heat treatment on high-alloy steels is quite novel. Chromium was found to delay the formation of cementite like silicon, and partitioning effects have been proved. However, in these steels, no pure partitioning happens, but a combination of tempering and partitioning. [5-8] Based on the results of TRIP steel, it is claimed in [9] for martensitic stainless steels that the stability of the retained austenite is influenced by its carbon content, grain size, and morphology. This investigation aims to determine and clarify the partitioning effects on the corresponding mechanical properties.

2. Experimental

2.1 Investigated Material

The chemical composition of the investigated steels can be found in Table 1. While X40Cr14 is a slightly modified standard steel grade, the "X25CrN13" is a non-standardized nitrogen alloyed plastic mold steel.

Table 2 Chemical composition of the investigated steels in wt.%

Steel	C	N	Cr	Si	Mn	Ni	V
X40Cr14	0.37	0.02	14.2	0.7	0.4	0.2	0.2
"X25CrN13"	0.24	0.12	13.2	0.2	0.3	0.4	0.2

2.2 Experimental procedure

Samples of 12 x 12 mm cross section and 120 mm in length were austenitized for 30 min at 1020°C ("X25CrN13") or 1050°C (X40Cr14) (=T_{aust}) in a chamber furnace and subsequently quenched to 270°C in a salt bath. After holding for 5 min. the samples were transferred to a second furnace with the desired quenching temperature T_q (80, 120 or 160°C) or cooled to room temperature. Afterwards a single 1 h tempering was conducted in a chamber furnace at tempering/partitioning temperatures T_{part} of 300 and 400°C. From this material, tensile test samples with a diameter of 6 mm were machined.

After tensile testing, samples were cut from the head as well from the non-constricted part with uniform elongation of the ruptured samples for further investigations. Contents of carbon, nitrogen and chromium in austenite were calculated with Thermocalc (database TCFE9).

2.3 Material investigation and testing conditions

Tensile samples were tested according to ISO 6892-1 on a Messphysik BETA 100 Makro. The amount of retained austenite was measured by XRD (Bruker D8 Advance) with a Mo-source, 40 kV using ASTM E975-13 in the necked und unnecked regions of the sample. The stability of the retained austenite was calculated by the change of its volume fraction during tensile testing, using the equation of Ludwigson and Berger [10]: $(V_{\gamma 0}-V_{\gamma})/V_{\gamma}=k_P*\varepsilon^p$. Thereby $V_{\gamma 0}$ is the initial RA fraction and V_{γ} represents to the RA content after straining, in this case at uniform elongation. The factor k_P indicates the stability of RA, with low values corresponding to a high stability. ε represents the true strain at uniform elongation. The factor p is a strain exponent related to the autocatalytic effect of the martensitic transformation, which can be considered as 1 for TRIP assisted steels.

3. Results and discussion

3.1 Results from tensile testing

The stress-strain curves of both steels for the partitioning temperature of 400°C with different quenching temperatures of 20, 80, 120 and 160°C are shown exemplarily in Figure 1. Both steels show a similar behavior with slightly higher values in strength and elongation for the "X25CrN13".

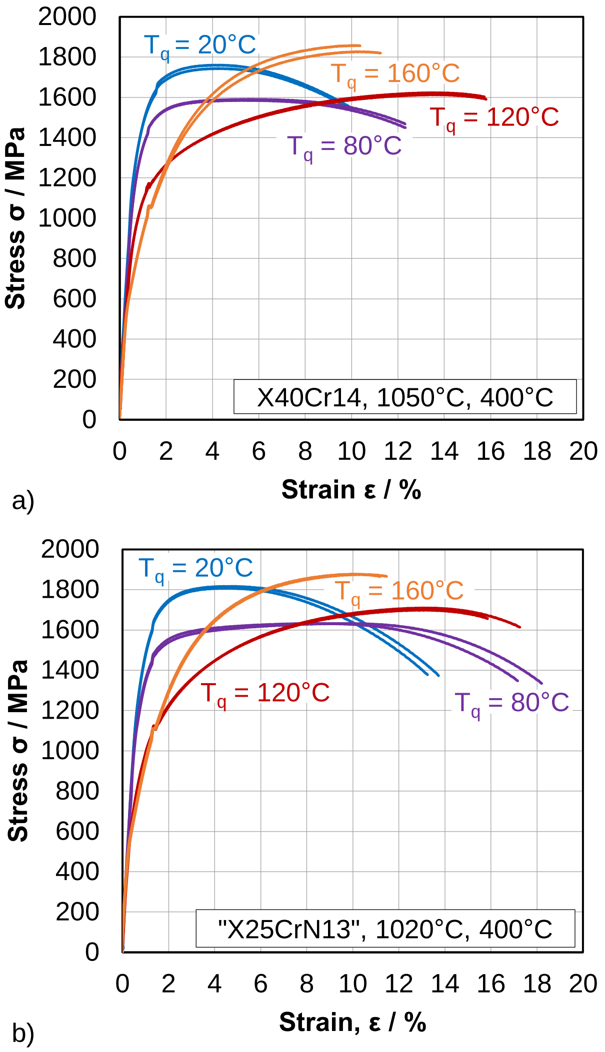


Figure 1 Stress-strain curves the T_q stands next to the curves of a) X40Cr14, T_{aust}=1050°C, T_{part}=400°C, b) "X25CrN13", T_{aust}=1020°C, T_{part}=400°C

Quenching to room temperature leads to a long elastic straining, a low uniform elongation (UE) of about 4 % followed by significant continuous necking and a total elongation of about 10 % (X40Cr14) and 13-14 % ("X25CrN13"). Tensile strength levels of ~1800MPa can be achieved with both steels. Increasing the quenching temperature T_q to 80°C and 120°C reduces the elastic behavior and tensile strength but increases uniform and total elongation (TE). The stress-strain curves show a long continuous increase in stress, which is typical for Q&P-treated steels and higher quenching temperatures, with a significant TRIP-effect, similar to results in [11, 12]. Increasing T_q further enhances the strengthening by the TRIP-effect, leading to highest tensile strength values, but reduces uniform and total elongation.

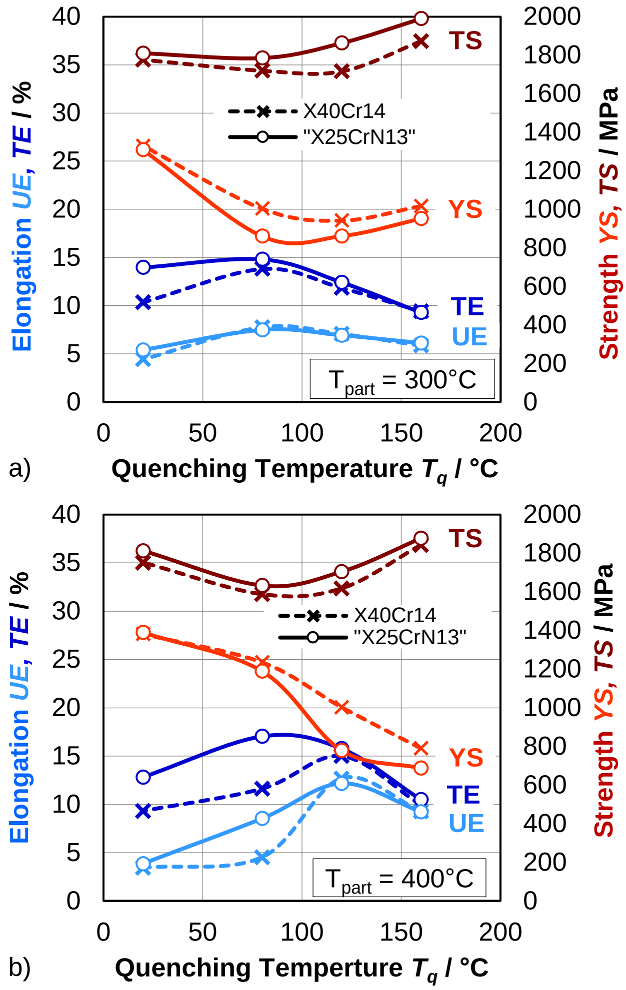
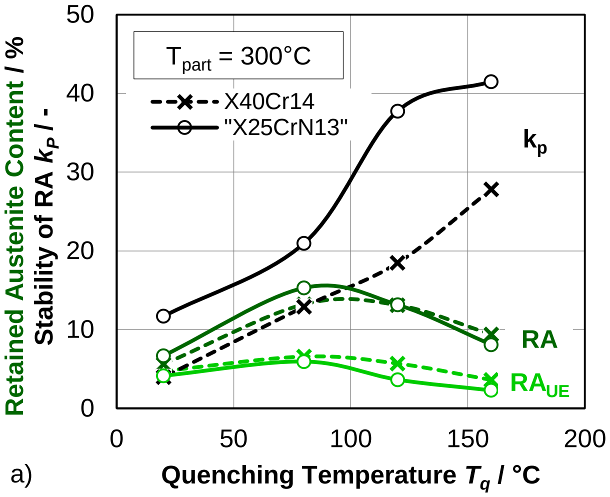


Figure 2 Mechanical properties, a) partitioning temperature T_{part}=300°C, b) partitioning temperature T_{part}=400°C

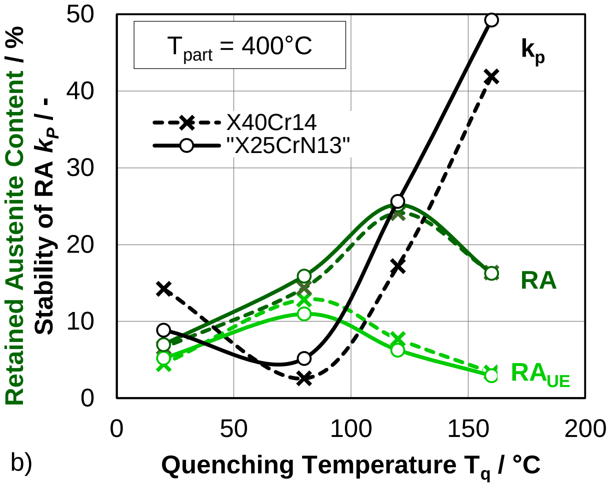
Figure 2 summarizes these results for both partitioning temperatures. Increasing the quenching temperature always leads to a slightly U-shaped behavior in tensile strength (TS) and a significant drop in yield strength (YS), mostly followed by a stabilization at high T_q. While yield strength reaches a minimum after partitioning at 300°C, there is a continuous drop at the higher T_{part} of 400°C. In reverse, uniform and total elongation always reach a maximum at medium quenching temperatures, whereby the maximum is stronger pronounced and shifted to higher T_q at the higher T_{part} of 400°C. Comparing the two steels, the X40Cr14 exhibits higher yield strength, lower tensile strength and similar elongation at higher T_q. The general behavior as a function of the quenching temperature corresponds well to medium-manganese steels in [11- 13].

3.2 Retained austenite and austenite stability

To understand this behavior, it is important to look at the retained austenite content and its stability expressed by the k_P-value in Figure 3. Furthermore, the composition of the austenite prior to quenching needs to be taken into consideration. While the calculated chromium content at austenitizing temperature is quite similar (13.2 and 13.7 %), the dissolved carbon and nitrogen contents is different with 0.31 %C and 0.02 %N for the X40Cr14 respectively 0.24 %C and 0.10 %N for the “X25CrN13”. This means that the main difference between these two steels is the carbon to nitrogen ratio.



a)



b)

Figure 3 Retained austenite and austenite stability, a) partitioning temperature T_{part}=300°C, b) partitioning temperature T_{part}=400°C

Thus, the retained austenite content of the “X25CrN13” in the undeformed condition (RA) is higher, but after uniform deformation this behavior reverses (RA_{UE}). Consequently, the stability expressed by the lower k_P-value of the X40Cr14 corresponds to a higher stability of the retained austenite. Rising the partitioning temperature from 300 to 400°C shifts the RA content prior to the deformation to higher quenching temperatures and significantly higher values for both steels, which corresponds to a stronger stabilization during partitioning. Such behavior is well known from e.g. [11-13] as higher quenching temperatures lead to less martensite prior, and a lower carbon content in retained austenite after partitioning, resulting in a lower RA stability as well as a fresh martensite. The k_P-values of the two steels approach each other at the higher partitioning temperature. This is an indication that nitrogen partitioning might require higher temperatures than carbon partitioning due to a lower diffusion rate [14]. Note, the increased k_P-values at room temperature and partitioning at 400°C are most likely a result of the low retained austenite values and corresponding measurement inaccuracy.

3. Summary and conclusions

Partitioning effects, respectively the diffusion of carbon and nitrogen into retained austenite during a partitioning treatment, has a strong effect on the mechanical properties of martensitic stainless steels. In detail the following implications were found:

Rising quenching temperatures lead to reduces yield and tensile strength as well as to an increased ductility. At highest quenching temperatures tensile strength rises and ductility drops due to a strong TRIP effect.

A higher partitioning temperature shifts the maximum of retained austenite and ductility to higher quenching temperatures.

This behavior can be correlated with the stability of the retained austenite expressed by the k_P-value.

The nitrogen alloyed grade has a better ductility and tensile strength as well as a lower yield strength and requires a higher partitioning temperature for a full stabilization of the retained austenite.

Acknowledgments

The authors gratefully acknowledge the funding of the project by voestalpine Böhler Edelstahl GmbH & Co KG.

References

1) R. Schneider, J. Perko and G. Reithofer: Mater. Manuf. Process. **24** (2009) 903-908
2) B. C. De Cooman and J. G. Speer: Steel Res. Int. **77** (2006) 634-640
3) J. G. Speer, E. De Moor, K. O. Findley, D. K. Matlock, B. C. De Cooman and D. V. Edmonds: Metall. Mater. Trans. A **42** (2011) 3591-3601
4) D. Edmonds, K. He, F. Rizzo, B. C. De Cooman, D. K. Matlock and J. G. Speer: Mater. Sci. Eng. A **438–440** (2006), 25-34
5) Q. Huang, B. C. De Cooman, H. Biermann and J. Mola: Metall. Mater. Trans. A **47** (2016) 1947-1959
6) Q. Huang, C. Schröder, H. Biermann, O. Volkova and J. Mola, Steel Res. Int. **87** (2016) 1082-1094
7) S. Kresser, R. Schneider, H. Zunko and C. Sommitsch: J. Heat Treat. Mater. **76** (2021) 120-131
8) J. Mola and B. C. De Cooman: Metall. Mater. Trans. A **44** (2013) 946-967
9) B. Deng, Z. Hou, G. Wang and H. Yi: Metall. Mater. Trans. A **52** (2021) 4852-4864
10) D. C. Ludwigson, J. A. Berger: J. Iron Steel Inst. **207** (1969) 63-69
11) S. Kaar, D. Krizan, R. Schneider, C. Béal and C. Sommitsch: Metals 9 (2019) 1122
12) S. Kaar, D. Krizan, R. Schneider and C. Sommitsch: Steel Res. Int. **91** (2020) 2000181
13) R. Schneider, S. Kaar, S. Schneider, D. Krizan, C. Sommitsch, J. Heat Treat. Mater. **76** (2021) 445-457
14) H. Berns, E. Theissen: *Eisenwerkstoffe*, 4. Aufl., (Springer-Verlag, Berlin, 2008) pp. 16.