EFFECT OF AUSTENITIZING TEMPERATURE ON THE PHASE TRANSFORMATIONS OF Mn-Cr-Mo PIPE STEEL

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Abstract

The steel with 0.3% C – 1.2% Mn – 0.8% Cr – 0.2% Mo is intended for the production of seamless pipes in the Mannesmann method, i.e. by piercing of the round billet by skew rolling and subsequent longitudinal rolling on a pilgrim mill. The heating and finishing temperatures are relatively high and it is therefore necessary to know the continuous cooling transformation (CCT) diagrams in a wider range of temperature conditions. At a heating rate of 0.167 °C·s^{-1}, the temperature Ac$_3$ = 824 °C was determined dilatometrically for the investigated steel. Subsequently, two different austenitizing temperatures were chosen for dilatometric tests. Continuous cooling transformation diagrams with previous deformation (DCCT) were constructed after the compressive true strain of 0.35 with the strain rate of 1 s^{-1}, carried out at the appropriate austenitizing temperature of 860 °C and/or 1,000 °C. Dilatometric curves were obtained after cooling at constant rates in the range of 0.1 – 35 °C/s. Their mathematical processing was combined with metallographic analysis and hardness measurement of selected samples. After cooling at rates lower than about 0.8°C·s^{-1}, the structure consisted of ferrite, bainite and pearlite in varying proportions. Higher cooling rates led to an increasing share of martensite. In the high-temperature DCCT diagram, bainite plays a more significant role, and both the Ferrite-start and Pearlite-start curves are shifted towards longer times. This can be explained by the coarser initial austenitic grains after heating the samples to a temperature of 1,000 °C.

Keywords: Low-aloy steel, dilatometry, DCCT diagram, microstructure

1. INTRODUCTION

One of the key objectives of the steel industry is the increasing efficiency associated with cost savings for the production and processing of material. This can be achieved, among other things, by the technology of controlled rolling with the following controlled cooling from the finish-rolling temperature, which leads to the formation of the required fine-grained microstructure of the material and to the acquisition of the corresponding mechanical properties [1,2]. Knowledge of Continuous Cooling Transformation (CCT) diagrams plays a key role in this. The type and kinetics of individual phase transformations are mainly influenced by the chemical composition of the steel and the cooling rate [3-5]. However, the initial structure, which is the result of the previous thermo-mechanical processing, also plays an important role [6-10]. The aim of the work was to study the effect of austenitizing temperature on DCCT diagrams (i.e. with the effect of previous deformation) of low-alloy steel with 0.29 % C – 1.20 % Mn – 0.27 % Si – 0.78 % Cr – 0.21 % Mo – 0.030 % Al – 0.0097 % N. This steel is used to make the seamless pipes, which includes piercing of the billet by skew rolling and subsequent longitudinal rolling on a pilgrim mill. The range of forming temperatures is relatively wide and therefore it is advisable to develop and compare DCCT diagrams after significantly different austenitizing temperatures.

2.   EXPERIMENTAL PROCEDURES

The work was based on dilatometric tests, performed using a non-contact optical scanning system on a hot deformation simulator Gleeble 3800-GTC. The starting material was cuttings from thick-walled pierced

semi-products. From them, samples with a diameter of 6 mm and a length of 86 mm were taken parallel to the longitudinal axis of the rolled blanks and at an identical depth below the surface, and turned. First, the phase transformation temperatures Ac_1 = 747 °C and

Ac_3 = 824 °C were determined by analyzing the dilatation curve during slow heating at a rate of 0.167 °C·s^{-1} (i.e. 10 °C·min^{-1}) – see **Figure 1**. Based on these findings and considering the specific

Figure 1 Determination of transformation temperatures during slow heating

technological conditions when using the Mannesmann method of the seamless pipes' production, two different austenitizing temperatures were chosen for the construction of DCCT diagrams: 860 °C and 1000 °C.

The individual samples were resistively heated in the measured zone at a rate of 10 °C·s^{-1} to the selected austenitizing temperature and, after holding for 600 s, deformed by uniaxial compression at a strain rate of 1 s^{-1} to a true strain of 0.35. Immediately afterwards, they were cooled at selected constant rates (i.e. nominally 0.1 – 35 °C·s^{-1}) almost to room temperature. The registered dilatometric curves were analyzed using special CCT software (DSI) and the mathematical program Origin (OriginLab). **Figure 2** shows examples of the dilatation curve and its additional analysis using numerical derivation.
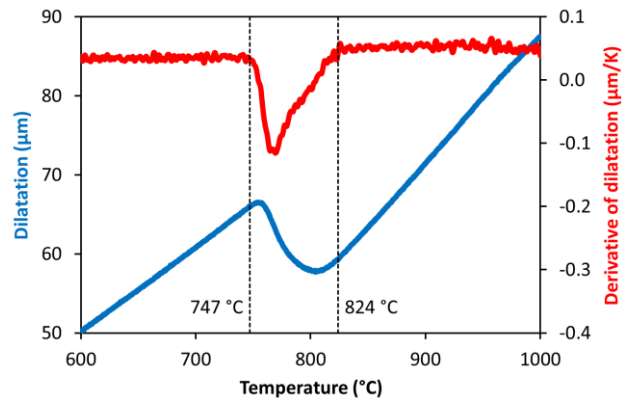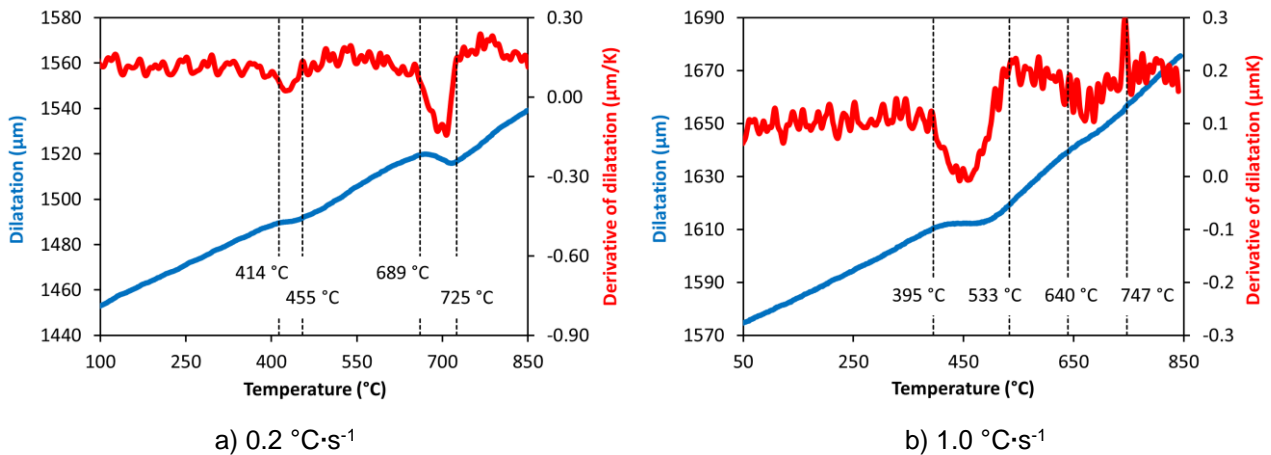

a) 0.2 °C·s^{-1}

b) 1.0 °C·s^{-1}

Figure 2 Analysis of dilatation curves after cooling from a temperature of 860 °C at different cooling rates

The temperatures and types of phase transformations determined in this way were verified in selected cases by metallographic analysis using light microscopy, or by measuring the hardness of HV 30 on the cross-section of the samples (always in half the length of the packed part). Micrographs in **Figure 3** document the effect of cooling rate on the resulting structure. **Table 1** shows the average values of measured hardness and phase components identified and approximately quantified by metallographic analysis. From left to right, the phase fractions are listed in decreasing amount, very small fractions of the given phase component are listed in parentheses (F = ferrite, P = pearlite, B = bainite, M = martenzite).
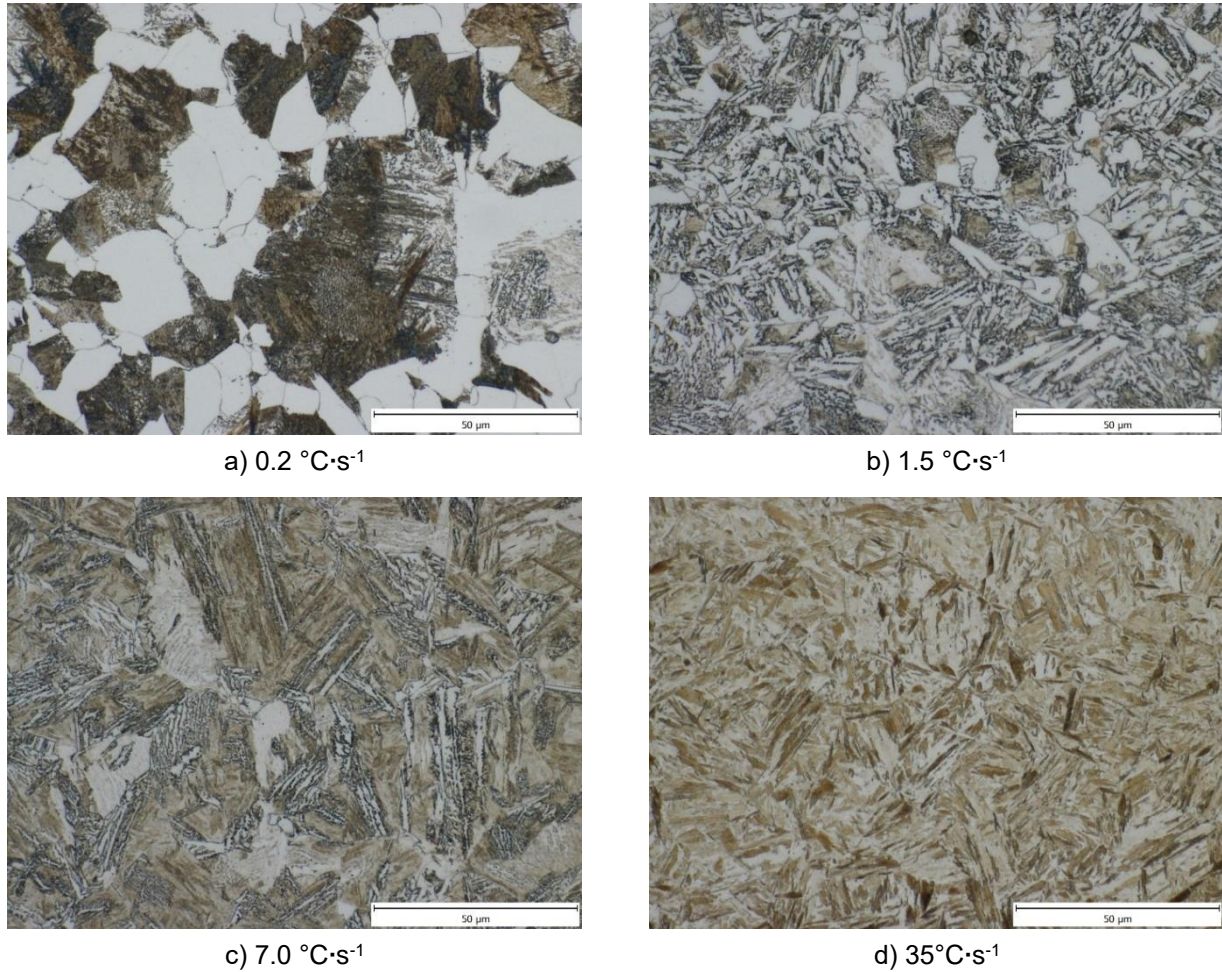
a) 0.2 °C·s⁻¹

b) 1.5 °C·s⁻¹

c) 7.0 °C·s⁻¹

d) 35°C·s⁻¹

Figure 3 Effect of cooling rate on the microstructure after cooling from a temperature of 1,000 °C

Table 1 Effect of cooling rate on phase composition and hardness

| Cooling rate (°C·s⁻¹) | Austenitizing temperature | | | |
| | 860 °C | | 1,000 °C | |
	Phase components	Hardness HV 30	Phase components	Hardness HV 30
0.1	F+P+B	228	–	–
0.2	–	–	B+F+P	263
0.4	F+B+P	272	B+F+(P)	271
0.6	–	–	B+F+(P)	289
1.0	F+B+M+(P)	313	B+F	298
1.5	B+M+F	352	B+(M)+(F)	309
2.0	–	–	B+M	333
3.0	M+B+(F)	401	–	–
4.0	–	–	B+M	383
5.0	–	–	B+M	414
6.0	M+B+(F)	466	–	–
7.0	–	–	M+(B)	483
10	M+(B)	519	–	–
35	M	569	M	570

3.   COMPARISON OF DCCT DIAGRAMS

On the basis of these three types of results, mostly closely correlated with each other, it was possible to set a low-temperature and a high-temperature DCCT diagram of the investigated steel – see **Figure 4**. The horizontal lines correspond to the experimentally determined temperature Ac_3 = 824 °C and specific austenitizing temperature (860 °C or 1,000 °C). Metallographic analysis proved to be necessary especially for samples with a minor occurrence of some phase components in the structure, because these are practically not detectable by dilatometric tests in the case of a volume fraction below approx. 5 %.
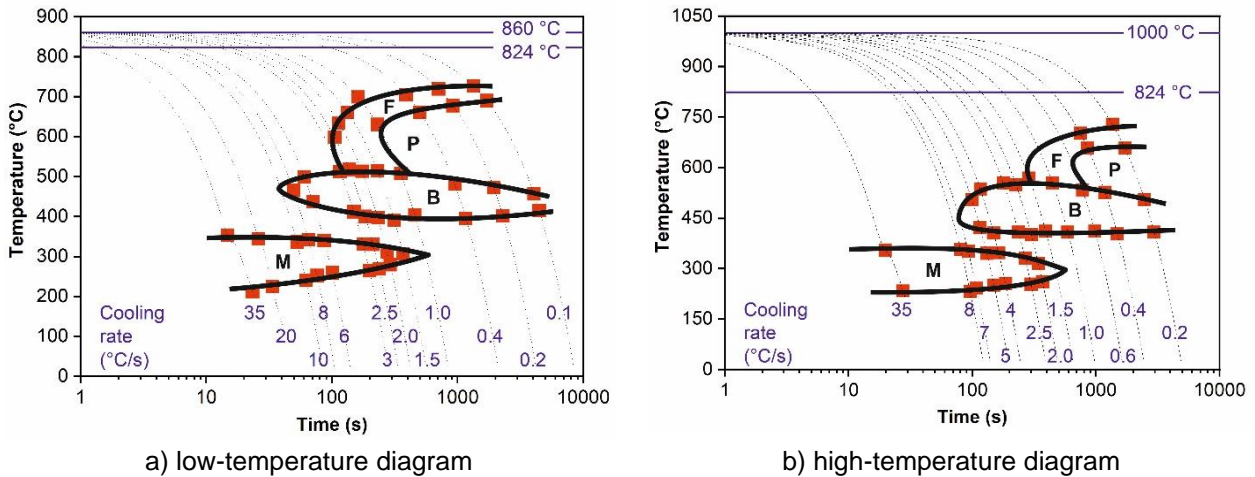

a) low-temperature diagram   b) high-temperature diagram

Figure 4 DCCT diagrams of the tested steel

After cooling at low rates, the structure is composed of ferrite, bainite, and pearlite in varying proportions. Conversely, high cooling rates are associated with the existence of a mixture of bainite and martensite, or only martensite. The temperatures of start of the individual phase transformations do not differ fundamentally when comparing the two diagrams. In the high-temperature diagram, however, a shift of the ferritic and pearlitic regions towards longer times (or lower cooling rates) is evident. To explain this phenomenon, an additional analysis was carried out, consisting of the etching of the prior austenitic grain boundaries in samples cooled at a rate of 35 °C·s⁻¹ (i.e. with a structure fully formed by martensite). The austenitic grains were fully recrystallized but showed a significantly different size as determined by the software QuickPHOTO INDUSTRIAL (PROMICRA). After austenitizing and deformation at a temperature of 860 °C, the mean grain size was 9.7 ± 0.9 μm, but after deformation at a temperature of 1,000 °C it was roughly twice (21.7 ± 2.0 μm; the data scatter was characterized by the confidence interval with a 95% confidence level). Thus, it was confirmed that a coarser austenitic grain is associated with a slowing down of the ferritic and pearlitic transformation, the grains or formations of which are originated by a diffusion mechanism [11,12]. The reason is the formation of a smaller amount of suitable nucleation sites.

Figure 5 documents the effect of cooling rate on the hardness of the samples in the case of low-temperature and high-temperature DCCT diagrams. The HV 30 hardness grows steadily with the increasing proportion of the product phases in quenching until the moment when the structure consists exclusively of martensite. The influence of austenitizing temperature is relatively small; the respective differences in hardness are the result of slightly different phase composition and grain size.
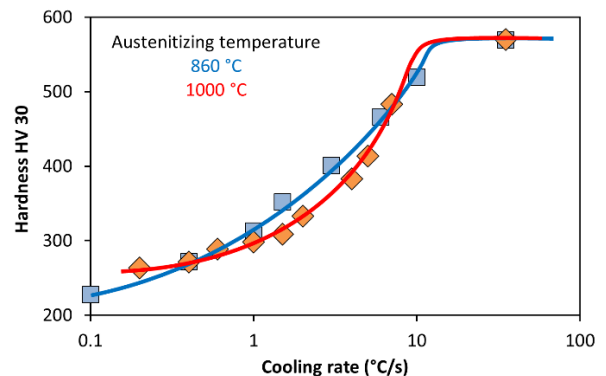

Figure 5 Hardness influenced by the cooling rate

4. CONCLUSIONS

DCCT diagrams of pipe steel low-alloyed with Mn, Cr and Mo were constructed and compared for very different austenitizing/deformation temperatures of 860 °C and 1,000 °C. Even a relatively very low cooling rate of 0.1 °C·s⁻¹ did not prevent the appearance of bainite in the resulting microstructure. Higher cooling rates led to an increasing share of martensite. In the high-temperature DCCT diagram, bainite plays a more significant role, and both the Ferrite-start and Pearlite-start curves are shifted towards the lower cooling rates. This is associated with the coarser initial austenitic grains after heating on temperature of 1,000 °C, as well as after high-temperature deformation followed by a long-lasting static recrystallization or even coarsening of the new grains.

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