APPLICATION OF ANALYSIS FOR MONITORING THE HARDEBILITY OF LOW ALLOY HIGH-STRENGTH STEEL

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Abstract

The paper deals with the effect of heat treatment parameters on mechanical properties and microstructure of low alloy high-strength steel 55 Cr3. The material standard of this steel defines the hardening temperature interval from 830 to 850 °C, which brings about the question of minimum soaking time in order to dissolve carbide particles and to homogenize austenite before quenching. The higher is the heating rate the higher is also the temperature that ensures perfect transformation of the initial microstructure into austenite and makes optimum conditions for desired final microstructure and properties of the steel. The dilatometric analysis performed on the samples simulating different conditions of austenitization confirmed that the incomplete austenitic transformation moved the curves of pearlitic and/or bainitic transformation in CCT diagram of the steel to the left, i.e. towards shorter times. After cooling the mixed microstructure containing not only the desired phases (bainite and/or martensite) but also a significant proportion of pearlite, including the original undissolved pearlite, was detected.

Keywords: Low alloy high-strength steel properties, heat treatment, dilatometric analysis, CCT diagram echanical properties, microstructure

1. INTRODUCTION

It is well-known that the parameters of heat treatment of structural steel significantly affect their final material properties. It is also well-known that the result of heat treatment can be influenced besides chemical composition by the initial microstructure, too, and that this microstructure has close relation to the manufacturing technology of steel semi-finished product. The presented paper describes the effect of lowering austenitizing temperature of rods made of the steel grade 55 Cr3 where the original austenitizing temperature 920 °C was lowered due to economic reasons down to 840 °C. Although such a low temperature is acceptable according to the material standard (EN 10089, annex D) [1], its application has changed the resulting microstructure and mechanical properties of the final product due to the uncompleted high temperature transformation into austenite. The aim of this paper is to present performed material analyses that allowed understand the structural response of the insufficiently heat-treated rods made of the steel 55 Cr3.

2. EXPERIMENTAL MATERIAL AND PERFORMED ANALYSES

Hot rolled rods of diameter 20 mm made of steel grade 55 Cr3 were used for experimental verification of the effect of heat treatment on the material properties and microstructure. Chemical composition of the rods is stated in **Table 1**. Rods were delivered in as-received state, i.e. after controlled cooling on Stelmor conveyor.

Table 1 Chemical composition of rod made of steel grade 55 Cr3, (mass %)

C	Mn	Si	P	S	Cu	Ni	Cr	Al	W	Mo	V	Nb
0.562	0.93	0.292	0.010	0.005	0.01	0.02	0.87	0.021	0.01	0.003	0.005	0.002

The performed experiment consisted of dilatometric measurements of transformation temperatures and construction of continuous cooling transformation (CCT) diagrams; all these experiments were carried out on dilatometer Bähr DIL 805 A by using the absolute method (direct record of the length expansion of the sample in relation to temperature). In order to explain how the undesirable microstructure formed during heat treatment after in-shop heat treatment, series of dilatometric samples were cooled down from austenitizing temperature 840 °C, with various cooling rates and the CCT diagram of the 55 Cr3 steel was determined by the dilatometric-metallographic method under the following conditions:

- austenitizing temperature 840 °C: holding time 3 s, cooling rates (in °C / s) 100, 9, 6, 3, 1,
- austenitizing temperature 920 °C, holding time 3 s, cooling rates (in °C / s) 9, 6, 3, 1.

Austenitizing temperature 920 °C was implemented into experimental program for comparison the new results with those obtained from previously routinely used method of austenitization.

3. EFFECT OF AUSTENITIZING TEMPERATURE ON MICROSTRUCTURE OD 55 Cr3 STEEL

First of all, the phase transformation temperatures A_{c1} and A_{c3} were experimentally determined by dilatometric measurement of slowly heated dilatometric samples. The values are stated in **Table 2** together with the results of calculations according to various formulas [2 - 4] All these calculated results were in quite good consistency with the measured ones. It is clear, therefore, that the suggested austenitization temperature 840 °C is quite acceptable for this steel because both measured and calculated values are lower more than 70 °C.

Table 2 Calculated values of transformation temperatures (°C)

According to:	A_{c1}	A_{c3}
Hougardy [2]	733	766
Trazska [3]	735	763
Kasatkin [4]	739	767

All individual cooling curves were plotted in the time-temperature axes and two CCT diagrams were built by combination of dilatometric and metallographic results, one CCT diagram is valid for austenitizing temperature 840 °C, the other for 920 °C, see **Figures 1a** and **1b**.

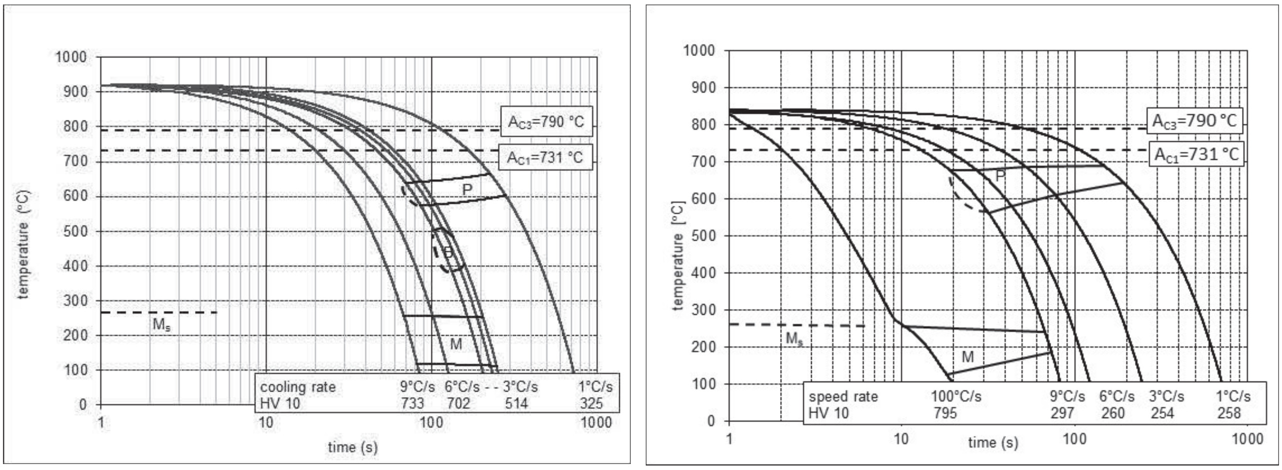

Figure 1 CCT diagram of steel 55 Cr3 austenitized at (a) 840 °C, (b) 920 °C (M_s calc. acc. to Andrews [5, 6])

Results of metallographic analysis, which is an integral part of building a CCT diagram aimed in qualitative and/or quantitative determination of the individual phases appearing in the steel depending on the individual cooling rate. The phases present in the microstructure are stated in **Table 3**, together with the corresponding hardness.

The dilatometric and metallographic analysis was also performed on a sample in the as-delivered state and on a sample that was cooled down after heating to 840 °C and 3-minute dwell at this temperature in the high speed (100 °C / s). This sample was chosen in order to reveal the effect of austenitization temperature on the resulting microstructure. The dilatometric record of the both samples austenitized at 840 °C with dwell time for 3 seconds and 3 minutes is shown in **Figure 2**, from which it is clear that the resulting structure is the same, fully martensitic, but the longer dwell time reflected in lower transformation temperature and higher hardness (see **Table 3**), most probably as a results of full pearlite decomposition and/or carbide dissolution during longer time that the sample spent at high temperature.

Table 3 Effect of cooling rate on phases and hardness in the steel, austenitizing temperature 840 and 920 °C

Cooling rate	**Austenitized at 840 °C / 3 s**		**Austenitized at 920 °C / 3 s**	
(°C / s)	**Microstructure**	**Hardness HV 10**	**Microstructure**	**Hardness HV 10**
100	M	795	-	-
100	M	863 *	-	-
9	P(B)	297	M+B	733
6	P(B)	260	M+B	702
3	P	254	M+B+(P)	514
1	P	258	P	325

* - dwell at austenitizing temperature for 3 minutes

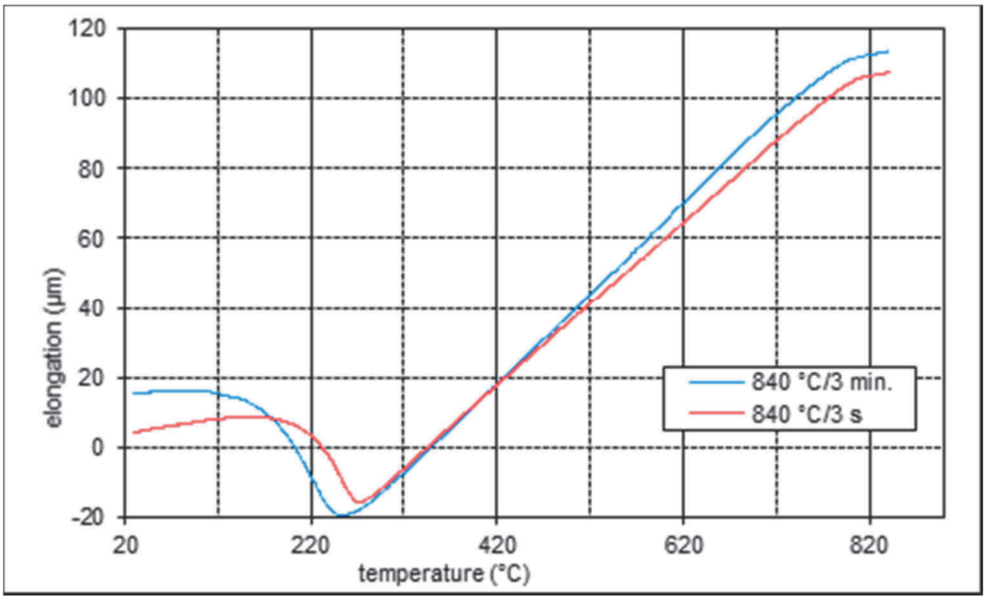

Figure 2 Record of dilatometric measurements of samples austenitized at 840°C with dwell 3 s and 3 min.[7]

Nevertheless, the structural changes between these two samples were so subtle that they had not mirrored in the microstructure, as can be seen in the comparison of microstructures shown in **Figure 3**. However, the higher austenitizing temperature shifted the beginning of the pearlitic transformation to longer timer and also allowed bainite to appear in the microstructure, compare **Figures 1a** and **1b**. Therefore, when compared sample austenitized at 840°C / 3 s and 920 °C / 3 s and cooled down at rate 6 °C / s, the microstructures and also material properties are quite different; sample austenitized at 840 °C transformed into a mixture of pearlite and bainite (**Figure 4**), while sample cooled down from 920 °C transformed into martensite with a small portion of bainite (**Figure 5**). This sample had also nearly three times higher hardness (702 versus 260 HV).

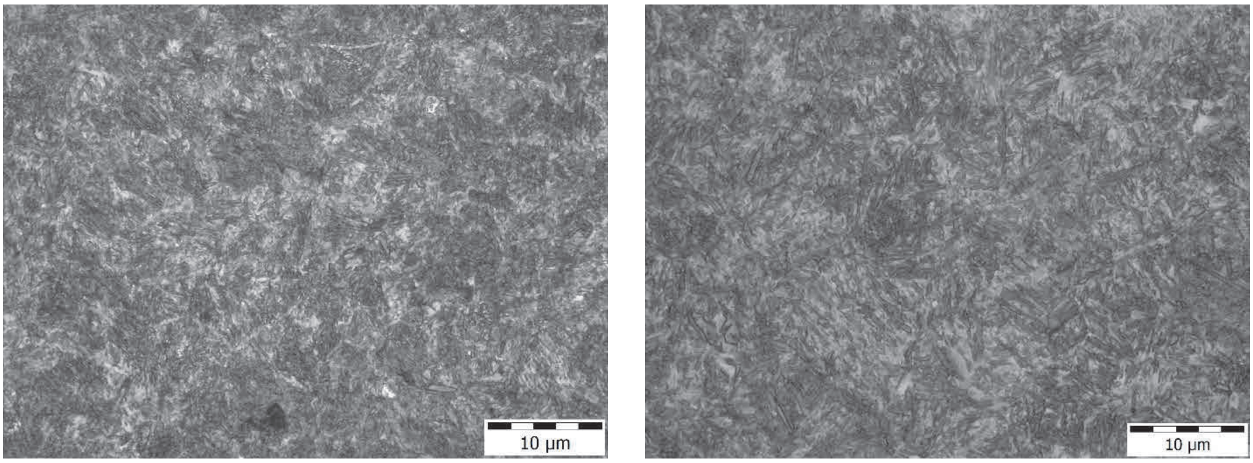

Figure 3 Detail of microstructure after heat treatment at 840 °C / 3 s / 100 °C / s (left) and 840 °C / 3 min / 100 °C / s (right)

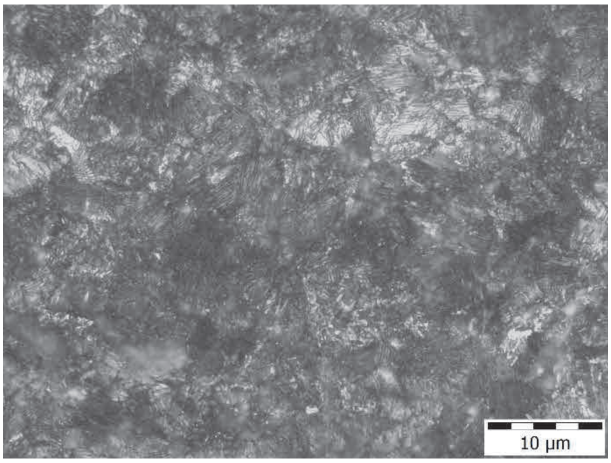

Figure 4 Microstructure of steel 55 Cr3 austenitized at 840 °C / 3 s/ 6 °C / s

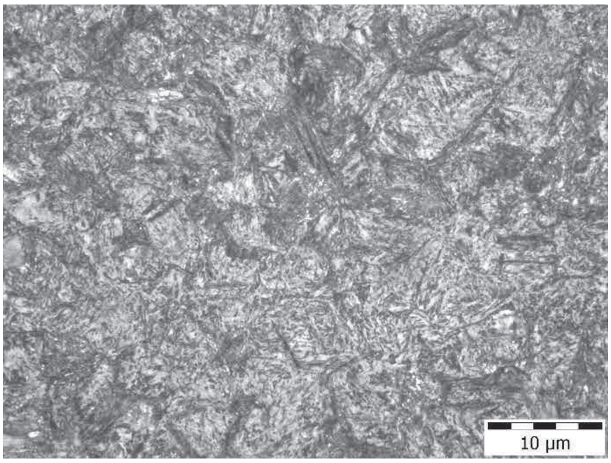

Figure 5 Microstructure of steel 55 Cr3 austenitized at 920 °C / 3 s / 6 °C / s

The explanation for such a material behaviour during austenitizing at different temperatures was found during evaluation of dilatometric records of these samples. As can be seen in **Figure 6**, the transformation into austenite started in both cases at the same temperature (around 770 °C), but in the sample austenitized at 840 °C the austenitizing was not completely finished due to fast heating rate and very short dwell time that did not allow necessary diffusion processes accomplishing the transformation. It is generally known that the formation of austenite takes place at temperatures higher than the transition temperature A_{c3} and the whole process can be divided into three stages:

- transformation of pearlite into austenite, which starts with cementite dissolution followed by the transformation of ferrite,
- dissolution of carbides, particularly in case of steels alloyed by strong carbide forming elements,
- homogenization of austenite.

The fact that transformation of the steel at 840 °C did not completely finished, namely the desired homogenization of austenite During the subsequent cooling, the austenite decomposed into pearlite (blue curve in **Figure 6**). On the other hand, in the second case, when austenitization temperature was 920 °C, fully homogenized austenite transformed into mixture of martensite and bainite (see black line in **Figure 6**).

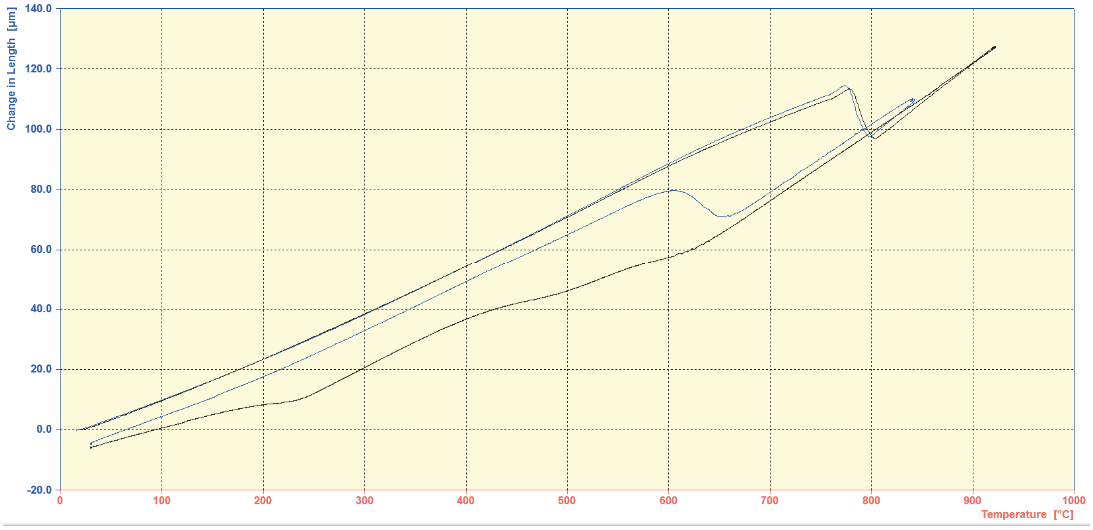

Figure 6 Record of dilatometric curves of heating and cooling of specimen austenitized at 840 and 920 °C

These results confirmed the fact that transformation depends not only on the temperature, but also on the heating rate and dwell time. The higher is heating rate the higher is also the temperature that ensures perfect transformation of the initial microstructure into austenite and makes the optimum conditions for obtaining the desired final microstructure and properties of steel. Fast heating, short holding time and low austenitizing temperature 840 °C, which are used in the manufacturing of the rods, do not allow the above described austenitizing stages to completely finish. Such conditions of incomplete austenitic transformation then move the curves of pearlitic and/or bainitic transformation in CCT diagram to the left, i.e. towards shorter times (higher cooling rate). After cooling the mixed microstructure contained not only the desired phases (bainite and/or martensite) but also a significant proportion of pearlite, including the original undissolved pearlite.

4. CONCLUSION

Although material standard EN 10089 specifies the temperature of austenitization as low as 840 °C (according to the information table), the performed experimental work showed that in order to obtain desirable material properties, it is necessary to set up appropriate heating and cooling conditions. When an extremely short dwell time at such a low temperature is used, austenitization is not completed at 840 °C and during subsequent cooling the nonequilibrium austenite decomposes into a soft mixture of pearlite and bainite instead of hard martensitic microstructure.

The above stated example shows the importance of knowledge of the principles of material design and also material behaviour during its processing. The sole pressure towards increasing productivity thus can bring about considerable difficulties.

ACKNOWLEDGEMENTS

This paper was created in the frame of the Project No. LO1203 "Regional Materials Science and Technology Centre-Feasibility Program" funded by Ministry of Education, Youth and Sports of the Czech Republic.

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