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Original Research Article

The influence of austenitization temperature on phase transformations of supercooled austenite in low-alloy steels with high resistance to abrasion wear

Beata Białobrzeska [a,*], *Rafał Dziurka* [b], *Andrzej Żak* [a], *Piotr Bała* [b]

[a] *Department of Materials Science, Welding and Strength of Materials, Wrocław University of Technology, 50-370 Wrocław, Poland*

[b] *Department of Physical Metallurgy and Powder Metallurgy, AGH University of Science and Technology, 30-059 Kraków, Poland*

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ABSTRACT

The paper presents continuous cooling transformation (CCT) diagram of selected low-alloy steel with high resistance to abrasion. Samples were prepared from examined material in as delivered conditions, then were austenitized at 900, 1000, 1100 and 1200 °C for 20 min, and then cooled with the rates of $V_{800-500} = 50, 10, 5, 1, 0.5, 0.1$ °C/s. During the dilatometric research, the critical temperatures were defined as well as the critical points specified for different cooling rates were designated. In addition, metallographic documentation of received microstructures after dilatometric investigations was prepared and hardness measurement was performed. The increase in the austenitizing temperature caused changes in the temperature of M_S and in the size of the martensite laths. What is more, the increase in the austenitizing temperature in the case of the analyzed steel caused a displacement of the bainitic and diffusion transformations to longer times. During the analysis using the TEM and SEM it was found that the size of the austenite grains is largely controlled by precipitates of the nitrides of AlN, TiN and carbides, mainly Cr_7C_3 and $M_{23}C_6$.

1. Introduction

Martensitic steels with boron have been successfully used in the construction of machine elements in order to increase the durability of those elements that are subject to abrasive wear [1,2]. However, the construction of many devices requires connecting these components using a thermal treatment, such as welding. Due to the fact that welding is a high-temperature technology, it may cause degradation of the favourable mechanical properties of these steels by changing the microstructure. These changes are particularly likely to affect the morphology and the size of the martensite or bainite needles.

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[*] *Corresponding author.*
E-mail address: beata.bialobrzeska@pwr.edu.pl (B. Białobrzeska).

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So far, research has focused on the analysis of the effect of the austenitizing temperature on the properties, such as resistance to abrasive wear, impact strength, tensile strength, percentage elongation and reduction of area [3,4]. During the study it has been noted the pronounced effect of the austenite grain size on the morphology of the martensite and the mechanical properties. However, to be able to influence deliberately these properties and thereby protect them from degradation under the influence of temperature, these studies should be supplemented by an analysis of the effect of the austenitizing temperature on the phase transformations occurring in the steels with boron with high resistance to abrasive wear. This research does not analyze the influence of the boron to the structural transformations but it is need to be mentioned that boron significantly affects the diffusion processes in these steels, transiting them towards longer times [5]. However, the presence of boron, while improving the hardenability, can simultaneously cause the austenite grain growth [6,7] which on subsequent transformations has a major impact. Furthermore, the higher the austenitizing temperature is, the more dissolution of carbides and nitrides there is (which block the movement of the grain boundaries, leading to their failure to grow), thereby enriching the matrix in carbon and alloying elements. Thus the phenomena associated with an increased austenitizing temperature, which are directly related to the growth of the grain, are also indirectly related to the effects of the carbides and nitrides of the alloying elements dissolved in the matrix.

The following article shows CCT diagrams and their analysis supplemented with characteristic morphology of martensite and precipitates in the example of Hardox 450, which belongs to the group of boron steels with increased resistance to abrasive wear.

The development of these diagrams has a practical importance. Although for this study the steel Hardox 450 was chosen, due to its extensive use, but this group of steel also includes grades such as B27, which are delivered after a hot rolling with the suggestion of carrying out the heat treatment by the user. As already mentioned, one of the techniques of connecting the components made of these steels is welding and, as is suggested by the manufacturers, the welding joint must be heat treated. Thus, despite the fact that the most part of these steels are supplied after a treatment consisting of quenching and tempering, in this connection the carrying out of the following analysis appears to be reasonable.

Table 1 – Selected mechanical properties of the investigated steel in the as delivered condition.

	$R_{p0.2}$ [MPa]	Hardness [HB]	KCV_{-20} [J/cm^2]
Manufacturer's data [8]	1100–1300	425–475	27

2. Materials and methods

For the tests, Hardox 450, a material from a group of low-alloy boron steels with a high resistance to abrasive wear, was selected. The chemical composition and mechanical properties of the analyzed material (according to the manufacturer's data and the research data) are presented in Tables 1 and 2. The plate thickness was 30 mm. A chemical composition analysis was performed with a spectral method using a glow-discharge spectrometer. The content of oxygen and nitrogen was measured using a NO analyzer.

To perform austenite grain growth analysis, samples were austenitized for a holding time of 20 minutes in temperatures of 900, 1000, 1100 and 1200 °C and then quenched in water. After each heat treatment, the specimens of the prior austenite grain were tempered at 250 °C for 30 min, in order to retain the detail of the austenite microstructure and to allow identification of the prior austenite grain boundaries. The samples were etched with 5% picric acid at 55 °C in accordance with the standard PN-H-04503:1961P (what corresponds to international standard ASTM E407-07). The measurements of austenite grain size were performed using the program NIS Elements. Each average austenite grain size was evaluated from 100 measurements.

Dilatometric researches were performed using the dilatometer Linseis L78 R.I.T.A. The Ø 3 mm × 10 mm samples were obtained from examined material in as delivered condition. Samples were heated to temperatures of 900, 1000, 1100 and 1200 °C at a rate of 5 °C/s. Holding time at austenitization temperature was 20 min. Then samples were cooled with rates of: $V_{800-500}$ = 50, 10, 5, 1, 0.5 and 0.1 °C/s, the change in extension of samples depending on temperature was recorded. A digital recording of the dilatograms allowed its subsequent differentiation to precisely define the temperature of the subsequent phase transformations. Based on characteristic points read from the differential curves, the CCT phase diagram for austenitizing temperatures was created.

The microstructure was analyzed by light microscopy (LM), scanning electron microscopy (SEM), and transmission electron microscopy (TEM). The samples used to LM and SEM observations were etched with 5% HNO_3. The X-ray microanalyzer EDX coupled with a scanning microscope was used to

Table 2 – Chemical composition of the investigated steel [4].

Element	C [wt.%]	Mn [wt.%]	Si [wt.%]	P [wt.%]	S [wt.%]	Ni [wt.%]	Cr [wt.%]	V [wt.%]	Al [wt.%]	Ti [wt.%]
Content of elements	0.223	1.32	0.489	0.009	0.004	0.044	0.784	0.004	0.035	0.02
Element	Nb [wt.%]	B [wt.%]	Cu [wt.%]	Co [wt.%]	Mo [wt.%]	As [wt.%]	Pb [wt.%]	O [ppm]	N [ppm]	
Content of elements	0.005	0.0011	0.015	0.016	0.012	0.009	0.002	42	34	