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Original Research Article

The influence of austenitizing temperature on prior austenite grain size and resistance to abrasion wear of selected low-alloy boron steel

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ABSTRACT

This study forms part of the current research on modern steel groups with higher resistance to abrasive wear. In order to reduce the intensity of wear processes, and also to minimize their impact, the immediate priority seems to be a search for a correlation between the chemical composition and structure of these materials and their properties. In this paper, the correlation between prior austenite grain size and wear resistance to abrasion were researched. The growth of austenite grains is an important factor in the analysis of the microstructure, as the grain size has an effect on the kinetics of phase transformation. The wear behavior has been investigated using GOST (Russian) standard T-07 wear test equipment in which the steel samples were worn by coarse alumina particles (grit size #90). The wear of the steels was evaluated by weight loss and their wear mechanisms were investigated using scanning electron microscopy. The abrasive wear mechanisms for analyzed low-alloy steels with boron additions were micro-cutting, micro-chips removal and micro-plowing. After the test it was stated that with an increase in austenite grain size, the intensity of wear increases, and the resistance to abrasive wear reduces, both in a linear manner.

1. Introduction

Analysis of the criteria for selection of structural materials for highly loaded machine elements (mainly in the mining, agriculture and transport industries) indicates that the primary factors that hamper durability are working units exposed to abrasive wear and dynamic loads. Dudzinski et al. [1] suggest that desirable features of these units can be summarized as:

- high resistance to abrasive wear;
- ability to carry dynamic loads;
- homogeneity of properties (i.e. the microstructure) through the whole cross-section of the element;
- weldability; and

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- resistance to degradation processes associated with corrosion and ageing processes.

These criteria, according to information from the leading manufacturers of steel, are acceptable for low-alloy steels with boron addition. In the 1930s, it was already observed that the addition of boron significantly increased the hardenability of low and medium carbon steel. As a result of this research, the group of weldable bainitic steels with tensile strengths of up to 1200 MPa was obtained. Production of boron steels with high resistances to abrasive wear began in the mid-1950s. At that time, Japanese ironworks JFE Steel Corporation began manufacturing the JFE EVERHARD steel plates, which were recommended for use in machine components exposed to abrasive wear [2]. In Europe, this type of steel was produced for the first time in 1970 by the Swedish steel company SAAB–Oxelösund [3]. Hardox 400 steel produced by the Swedish company SSAB was characterized by low carbon content, a simple chemical composition, simple microstructure and high hardenability achieved by boron addition. Recently it has been noticed that the application of low-alloy steels with high resistance to abrasive wear became more diverse. Up until now, 7 grades of Hardox steels have already been produced, viz. Hardox HiTuf, Hardox 400, Hardox 450, Hardox 500, Hardox 550, Hardox 600 and Hardox Extreme. Many manufacturers produce similar steel grades as: Weldox, Domex i Armox (SSAB), Ovako, Ramor, Raex, B13, B24, B24CR, B27, B27CR (Rautaruukki), 20MCB5, 23MCB5, 28MCB5, 30MCB5 (Zerneri Accai), XAR, TBL (ThyssenKrupp Steel Europe AG), Dillidur (Dillinger Hütte GTS), Durostat, Brinar (Grobblech GmbH), Fora, Creusabro (Industeel), Quard (NLMK Clabecq), HTK (Hut-Trans Katowice), Abrazo (TATA Steel Group), Endura (TITUS Steel), Sumihard (SUMITOMO Metal), JFE-EH (JFE EVERHARD Corporation), Armotec (Armotec Ltd). However, knowledge about these advanced materials is far from complete. In the material cards, the manufacturers present only the basic mechanical properties of these steels.

A very important factor to determine the microstructure of these steels formed during decomposition of undercooled austenite is hardenability. The main factors influencing the hardenability of steels are as follows: the chemical composition of steel, prior austenite grain size, uniformity of chemical composition of austenite, and the content of undissolved non-metallic inclusions [4]. Austenite grain growth occurs during hot working processes such as quenching, welding or hot rolling. Austenite grain size strongly influences the kinetics of phase transformation during the cooling cycle [5,6]. Some investigations on the grain growth kinetics for low carbon steel and micro-alloyed steel have been already reported [6–8]; yet much still needs to be explored to analyze the influence of austenitization temperature on austenite grain growth for low-alloy boron steels, with a high resistance to abrasive wear. Additionally, the influence of the size of the structural components on the resistance to abrasive wear in steels has not yet been subject to rigorous research. An analysis of austenite grain growth as a function of austenitizing temperature of these steels seems to be reasonable, especially to protect degradation of their favorable mechanical properties. Therefore, we have found it expedient to show how austenite grain size and then resistance to abrasion wear depends upon austenitization temperature.

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

	$R_{p0.2}$ [MPa]	Hardness [HB]	KCV_{-20} [J/cm^2]
Manufacturer's data [9]	1100–1300	425–475	27

Table 2 – Chemical composition of the investigated steel.

Element		Manufacturer's data [9]	Spectral method
		Content of elements	
C	wt.%	0.23	0.223
Mn	wt.%	1.60	1.320
Si	wt.%	0.70	0.489
P	wt.%	0.025	0.009
S	wt.%	0.010	0.004
Ni	wt.%	0.25	0.044
Cr	wt.%	1.00	0.784
V	wt.%	No data	0.004
Al	wt.%	No data	0.035
Ti	wt.%	No data	0.020
Nb	wt.%	No data	0.005
B	wt.%	0.004	0.0011
Cu	wt.%	No data	0.015
Co	wt.%	No data	0.016
Mo	wt.%	0.25	0.012
As	wt.%	No data	0.009
Pb	wt.%	No data	0.002

2. Methods

For the tests, Hardox 450, the 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 analyzed material (according to the manufacturer's data and research data) are presented in Tables 1 and 2. The plate thickness was 30 mm. Chemical composition analysis was performed with a spectral method using a glow discharge spectrometer.

The metallographic studies were performed using a light microscope. Microstructure in the delivery condition of the investigated steel is presented in Fig. 1. The tested material in the delivery state showed a martensitic structure. Martensitic microstructure exhibits a high homogeneity and some features that can be described as being similar to tempered martensite, with precipitates of some non-metallic inclusions like titanium nitrides (amber rhombus). In addition, the areas in which the former austenite grain boundaries are reflected, can be distinguished.

Samples were austenitized at temperatures 900, 950, 1000, 1050 and 1100 °C for holding time of 20 min and then quenched in water. The choice of holing time of 20 min was motivated by previous results of research [10] where was investigated the effect of holding time and holding temperature on prior austenite grain size of selected low-alloy boron steel with high resistance to abrasion. Based on the main effect plots for