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Research Article

Heat Treatment Effect on Microstructure and Mechanical Properties of 36CrB4 steel

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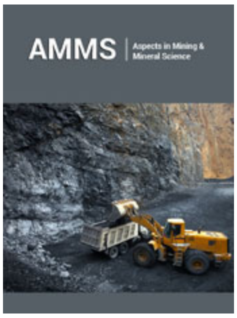

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Abstract

In this study, 36CrB4 boron steels were annealed at 870 °C for 2 hours and then cooled in oil. The steels cooled in oil were subjected to tempering at temperatures ranging from 480 to 520 °C for 2 hours to investigate the effects of quenching and tempering on their microstructure and mechanical properties. Tensile tests, impact tests, and Vickers microhardness tests were carried out. The results revealed that with tempering, the microstructure, which was initially martensitic after quenching, began to form bainite in addition to the tempered martensitic microstructure. It was observed that mechanical properties (except elongation) and hardness values significantly improved with quenching compared to the non-heat-treated samples but exhibited a decline with increasing tempering temperature.

Keywords: Boron steel; Quenching; Tempering; Mechanical properties; Impact energy

Introduction

Boron steels have significant properties such as high wear resistance, high hardness, easy machinability, and good mechanical properties [1-3]. Due to these properties, boron steels are widely used in the manufacturing of machines that require resistance to wear and friction, such as the processing bodies of soil processing machines and the automotive industry [4,5]. On the other hand, additional treatments have been done to improve the mechanical properties of these steels (wear, hardness, impact, etc.) such as different surface hardening methods (carburizing, nitriding, and boriding), adding specific elements [6], and thermal treatments such as quenching and tempering [7,8]. Corresponding to this, Suh et al. [9] showed that the microstructure and mechanical properties of boron steels change with thermal treatments. They obtained a martensite, tempered martensite-bainite, and multiphase microstructure by water cooling, oil cooling, and air cooling, respectively. In a comprehensive study conducted by Karademir [10] on boron steels (22MnB5), the strength value obtained from the sample heated to 1000 °C gives the same result as the heat treatment performed at 950 °C. It was determined that the decrease in hardness value was due to the coarsening of the bainite plates. According to the sample test results taken from the part shaped by heating at 800 °C, the hardness values did not reach the desired level. In addition, bainitic/martensitic transformation could not be achieved in the internal structure transformation. In another study conducted on 27MnCrB5, 30MnB5, and 34MnB5 boron steels [11], it was determined that the increase in hardening and tempering temperatures caused a decrease in tensile, yield, and fracture stress values. In the same study, the highest tensile, yield, and fracture stress values were obtained in the tempering process at 150 °C, followed by the tempering processes at 300 °C and 450 °C, respectively. In addition, it was determined that the tempering temperature was more effective than the austenitizing temperature on the tensile, yield, and fracture stress values. 36CrB4 boron steel is called low alloy steel and, in addition to being widely used in many industrial applications, it is also widely used today instead of 42CrMo4, which has high hardness and toughness behavior in terms of material cost [12]. In literature [13-16] there are a limited number of studies on the effect of heat treatment on the fatigue, friction and wear behavior of boron steels. However, there is no study on the effect of heat treatment on the tensile, hardness behavior and microstructure of 36CrB4 steel as a whole. The aim of the present study is to examine the effect of heat treatment (quenching and tempering) on the microstructure and mechanical properties (tensile, impact properties, and microhardness) of 36CrB4 boron steel.

Materials and Methods

In this study, cylindrical samples prepared from 36CrB4 boron steels with a diameter of 38mm and a length of 220mm were used. The chemical composition obtained with the optical emission spectrometry of the alloy is shown in Table 1. A heat treatment was applied to 36CrB4 boron steels in the form of preheating, annealing, quenching, and tempering, respectively. Firstly, the 36CrB4 boron steels were inserted into a heated furnace at 870 °C for 120min. after pre heated at 90min., quenched in oil, and then tempered at different temperatures of 480 °C and 520 °C for 120min, respectively, followed by air cooling (Figure 1). Before and after heat treatment, the microstructure of polished and etched specimens was studied using an optical microscope.

Table 1: Chemical composition of 36CrB4 steel (in wt.%).

Steel	C	Si	Mn	P	S	Cr	Mo	B
36CrB4	0.35	0.24	0.83	0.019	0.05	1.07	0.07	0.026

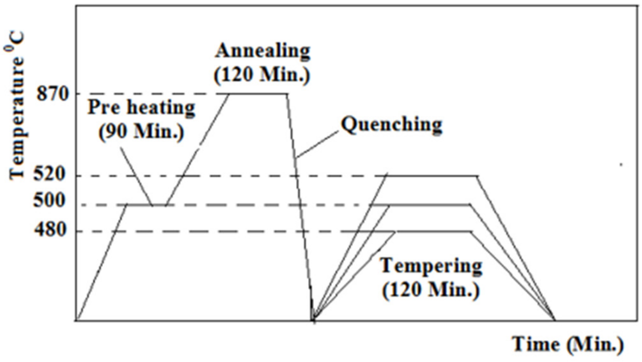

Figure 1: Temperature-time graph involving quenching and tempering.

Tensile, impact, and Vickers microhardness tests were carried out using a 100kN capacity servo hydraulic MTS Landmark tester (ASTM D1822), a 300 J capacity Instron 9350 Drop Tower Charpy impact tester (ASTM E23), and a TTS Matsuzawa HWMMT-X3 microhardness indenter at a load of 300g and a holding time of 10sec., respectively. The ultimate tensile stress (maximum stress on the stress-strain curve σ_{UT}), yield stress (stress at 0.2% offset strain σ_y) elongation were obtained from tensile tests. The measured tensile and impact test values were created by taking the average of 5 different test samples. In addition, Vickers hardness values and impact energies of 36CrB4 steels were also obtained in these processes. Before microhardness testing, a standard specimen was used for calibration. To ensure the reliability of the results, a minimum of five measurements were made at each depth to obtain average microhardness values. An Olympus BX51TRF-6 optical microscope was employed to investigate the microstructures of the polished and etched samples. More information on tensile and hardness tests can be found in Reference [17].

Result and Discussion

The microstructure of 36CrB4 boron steel before heat treatment is 55-60% pearlite and 40-45% ferrite (pearlite having a dark contrast and ferrite having a light contrast), as can be seen in Figure 2a. According to the ASTM E112 standard, the grain size is in the order of 3-4. While the microstructure after annealing (870 °C for 120min.) applied to 36CrB4 boron steel was obtained as austenite and dissolved perlite and ferrite (Figure 2b), the grain size determined according to the ASTM E112 standard increased to the range of 7-8 (Figure 2b). In a study by Er & Bozkurt [12] in which the wear properties of 36CrB4 boron steel were investigated, it was found that untreated 36CrB4boron steel had a pearlite and ferrite structure. In the same study, it has been observed that the structure of 36CrB4boron steel heat-treated at 850 °C for 1h and quenched in water immediately after austenitizing is predominantly dominated by the martensitic structure with need-like properties (Figure 2). In the present study, the microstructures after the quenching process in oil, the microstructure of 36CrB4 boron steel was determined to be 80-85% martensite, 5% ferrite, and the remaining bainite. In summary, after quenching in oil, the pearlite and ferritic phases generally transformed into a martensitic structure (Figure 3a). Finally, (Figure 3b & 3c) show the microstructures of tempered 36CrB4 boron steel. Tempered structure contains tempered martensite and a small amount (3-5%) of bainite (Figure 3b & 3c). The values of the σ_{UTS}, σ_y, elongation, Vickers hardness, and impact energy of 36CrB4 boron steel quenched and tempered in the range 480-520 °C together with untreated steels are given in Table 2. These values given in the table are average values obtained from many measurement results (Table 2).

Table 2: Mechanical properties of 36CrB4 boron steel versus different heat treatment process.

36CrB4 steel	Yield Stress (σ_y)	Tensile Stress (σ_{UTS})	Elongation (%)	Vickers Hardness	Impact Energy (J)
Untreated	690	988	9.8	301	17
After quenching	1198	1301	8.3	419	24
Temp. 480 °C	1121	1206	11.8	374	28
Temp. 500 °C	1073	1172	13.8	352	31
Temp. 520 °C	1004	1107	15.2	339	38

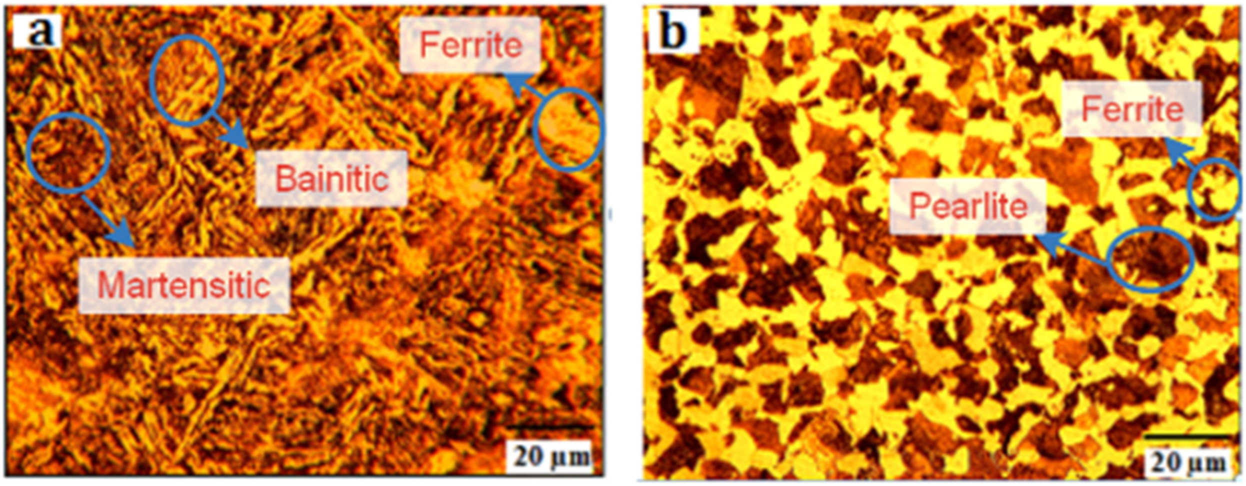

Figure 2: Optical micrographs of 36CrB4 boron steel before heat treatment (a), and after annealed at 870 °C for 120min (b).

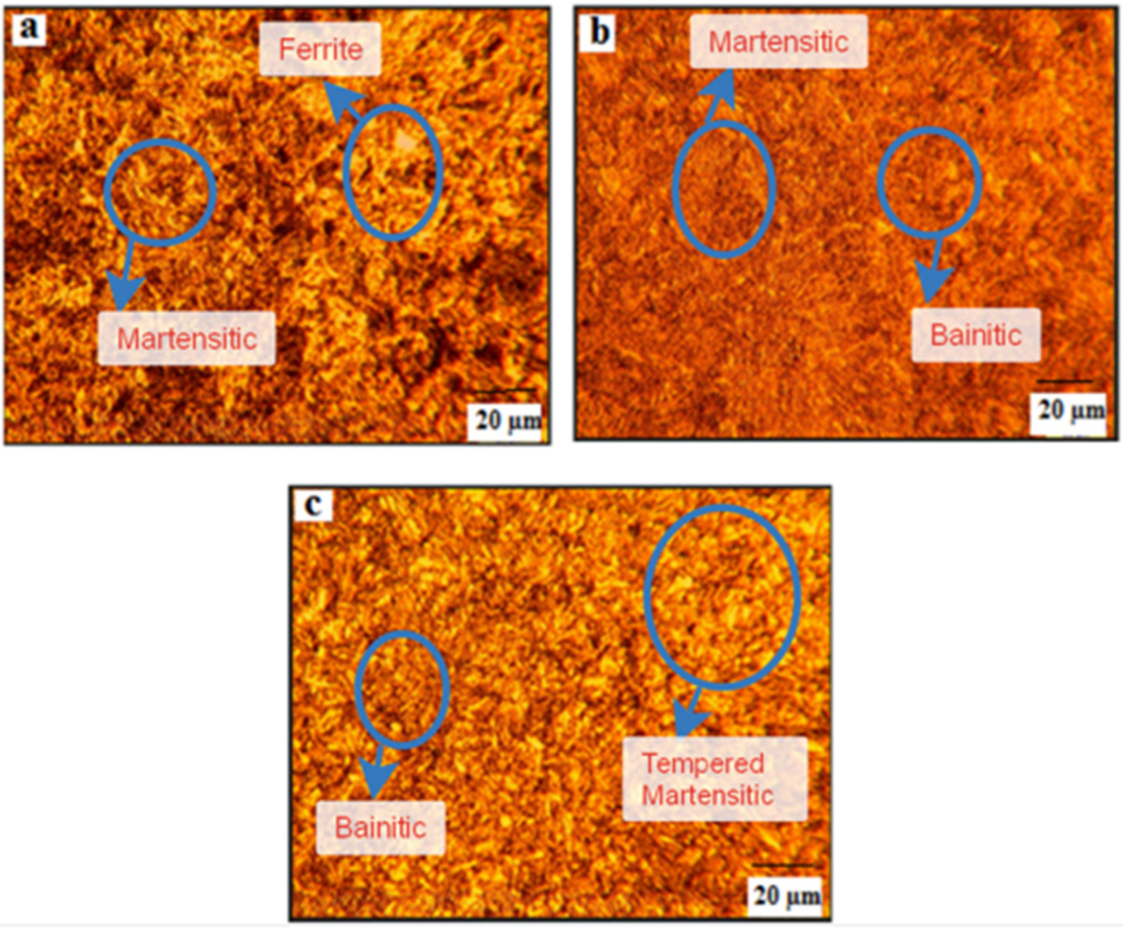

Figure 3: Optical micrographs of 36CrB4 boron steel after quenching in oil (a), after tempering at 480 (b) and 520 °C (c).

First of all, let's look at the relationship between untreated 36CrB4 boron steel and 36CrB4 boron steel quenched in oil after annealing at 870 °C for 120min. As stated in the literature [18-20], the quenching process, which is generally used for carbon steel and alloy steel with a carbon content of more than 0.3 percent, is used to obtain a high hardness martensitic level. In the present study, the structure of 36CrB4 boron steel is in the in the martensitic phase after the quenching process (Figure 3a). It is well known that the martensite phase is a hard form of crystalline steel structure, and it causes an increase in the hardness of the steel and thus its tensile properties to increase [21,22]. As can be seen from Table 2, the quenching process has a serious effect on the mechanical properties of 36CrB4 boron steel. There are some improvements in the mechanical properties of the quenched 36CrB4 boron steel compared to non-heat-treated 36CrB4 boron steel. With the quenching process, significant increases in σ_y, σ_{UTS}, Vickers hardness, and impact energy values other than elongation occurred compared to untreated samples. The reason for significant increases in mechanical properties can be said to be the internal stresses caused by point defects and dislocations during rapid solidification. Corresponding to this, Hutchinson et al. [23] showed that the martensite phase is a very strong phase with a high plastic flow stress, so the internal stresses created by point defects and dislocations that appear as a result of heat treatment can be very high indeed. In addition, it has been shown that increasing quenching temperature gives higher tensile strength and hardness values due to the formation of martensite structures [24].

Tempering is a heat treatment technique applied to ferrous alloys such as steel or cast iron to achieve greater toughness by reducing the hardness of the alloy. This process increases the workability and formability of the quenching hardened material and also reduces the risk of steel cracking or breaking due to internal stresses [25]. Now, let's look at the effect of tempering temperature on the mechanical properties obtained in this study. From Table 2, after quenching, elongation and impact energy values increase in 36CrB4 boron steel, while σ_y, σ_{UTS} and Vickers hardness values decrease with increasing tempering temperature. It is possible to explain the reason for this change in mechanical properties by the partial disappearance of internal stresses caused by quenching with increasing tempering temperatures. In addition, we think that another reason for this change is that the hard martensitic structure begins to transform into a bainitic structure with increasing tempering temperature. Similar results are seen in Calıgülü et al. study [26]. They showed that the reason for the decrease in Vickers hardness values with the tempering process (300-500 °C) applied to the 38MnVS6 and 41CrMo4 steels after quenching is the transformation of the martensitic structure into the bainitic structure, as well as the deterioration of the tetragonal crystal structure of the high hardness martensite and its transformation into carbide and low-carbon martensite structures. To sum up, it is possible to obtain sufficient hardness and high strength by controlling the tempering temperatures.

Conclusion

In this study, it was determined that quenching and tempering processes had a direct effect on the mechanical properties and microstructure of 36CrB4 boron steel. The obtained general results are expressed below.

a. The combination of ferrite and pearlite was observed before the quenching process, while after the quenching process, martensite structure was observed.

b. The quenching process has an effect on the mechanical properties of 36CrB4 boron steel. The σ_y, σ_{UTS}, Vickers hardness, and impact energy decrease with the quenching process due to internal stresses caused by dislocation locking.

c. As the tempering temperature increases, a bainitic phase with a martensitic structure begins to form.

d. With increasing tempering temperatures, the values of mechanical properties that increase after quenching begin to decrease. Elongation increases.

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