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THE EFFECT OF HARDENING HEAT TREATMENT ON AISI 1022 STEEL CONTAINING 15 AND 26 PPM BORON

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Abstract

Being one of the most commonly used low carbon steels, AISI 1022 steel has been melted at 1630 0C and supplemented by boron. After the casting process, AISI 1022 without boron and with 15 and 26 ppm boron were obtained, rolled and after having been kept in the furnace for 60 minutes at 875 0C for heat treatment, specimens were exposed to cooling process in air and water. The microstructures and hardness values of the specimens cooled in air and water were determined via optic microscope and with Vickers hardness method, respectively and the results were compared. From the microstructure images of materials without boron and with 15 and 26 ppm boron cooled in air, it can be seen that the particles are homogenous and there are spherical spots within the ferrite and polygonal TiN particles in some places. The microstructure images of the materials without boron and with 15 and 26 ppm boron cooled in water indicate that there are lath type martensite and widmanstatten ferrite. Specimens were compared according to their hardness results as vertical and parallel to rolling direction. While the hardness value of the specimen without boron in AISI 1022 material cooled in water was 142 HV5, this value increased to 160 HV5 in the material with 26 ppm boron content cooled in water. Approximately 18 HV5 increase was observed. It is assumed that the hardness of specimen increased since the boron remains as a solid melt within the material as a result of this fast cooling. In air cooling, on the other hand, no obvious difference was found in respect of hardness between the materials without boron and with 15 and 26 ppm boron.

Keywords: Boron, Boron steel, Heat treatment

1. Introduction

Being deemed as new in the industrial sphere, one of the application areas of boron and boron derivatives used in hundreds of different areas is steel industry [1]. Boron, in steel industry, is known to bring in a high rate of hardening capability to steel into which it is added as an alloying element [2,3]. Boron steels have relatively low mechanical characteristics before heat treatment [4].

When the boron is cooled down fast (quenching fast) and kept as solid melt within the grain, it provides the greatest effect on hardening. When the ratio of boron exceeds 600 ppm, hardness ratio reduces and the hot-working problems occur [5].

There are hundreds of boron steel types. Most of the boron steels are alloyed with Mn and Cr. In some cases, they contain Ni and Mo. Carbon ratios vary between 0,15% and 0,45%. Boron steels are used as hardened, tempered and under surface hardened conditions in some cases. Total boron content shouldn't exceed 0,006% (60 ppm) including insoluble boron compounds. [6]. Boron steels are primarily deoxidized with aluminum. As a result of the deoxidization, 0,03% aluminum left in the structure. Boron steels are generally (with 0,03% Ti) also treated with Nitriding process [7,8,9,10,11].

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In this study, AISI 1022 steel out of the low carbon steels was chosen due to its widespread use. AISI 1022 steel is generally utilized in bolts, nuts, machine bodies and parts, tank tracks and bullet casings [12]. Since the affinity of boron against oxygen and nitrogen is very high, it was thought to add 400 ppm aluminum and 400 ppm titanium to protect boron from oxygen and nitrogen, respectively. The microstructures of AISI 1022 steel without boron and with 15 and 26 ppm boron were examined by means of optic microscope after heat treatment and Vickers hardness results were compared.

2. Material and Method

In this study, the chemical analysis of the AISI 1022 steel, provided from Saka Iron Steel/Karabük,Turkey, was carried out in order to determine the ratios of boron, aluminum and titanium in it and to precisely calculate the boron, aluminium and titanium amounts that are needed to be added. The average results of the chemical analyses carried out at different regions of the AISI 1022 steel casting are given in Table 1.

After the melting process of the AISI 1022 steel in a 35 kg melting capasity non-vacuum induction furnace at 1635 ºC, the pearlite powder was applied on the liquid material and a thin layer of slags was formed on the surface. The layer created by the pearlite powder was taken out with a cold metal rod from over the melt while adding aluminum, titanium and boron and during the casting process. Thanks to this process, the mixture of oxygen and nitrogen to the melt in the non-vacuum induction furnace from the air was kept at the minimum level. The melt was cast in square-shaped ceramic moulds in 30x30 mm thickness heated until 450 ºC and it was cooled in the air. The obtained square-shaped materials at 30x30 mm in size were kept at 1200 ºC for 60 minutes in the furnace at the laboratories of Gebze TÜBİTAK Marmara Research Center Materials Institute, and they were exposed to deformation at 80 % by rolling them at two passes in a hot rolling device with brand of HILLE. The hot deformation's second rolling out pass temperature was given close attention to be in the austenite (950 ºC) region. The reason for being the AISI 1022 steel at austenite region is easy to perform hot deformation.

Table 1. Comparison of chemical analyses of AISI 1022 steel containing boron in different ratios by % weight

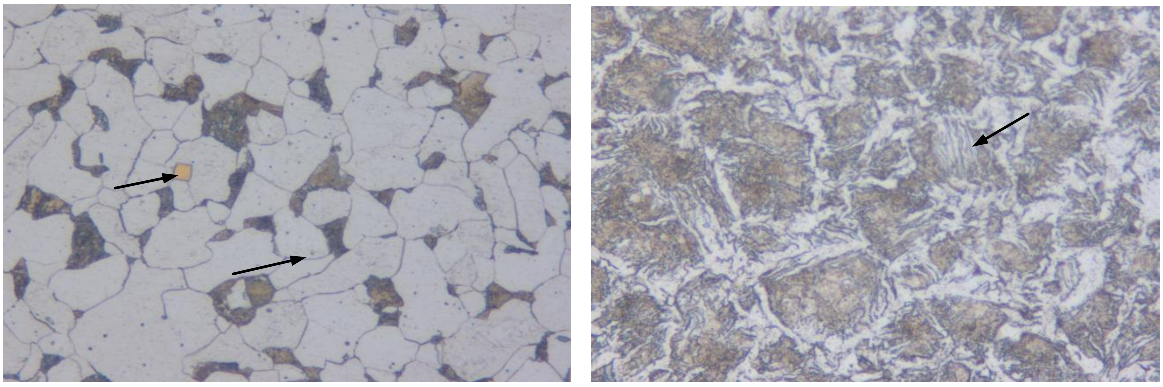
Casting No	% C	% Mn	% Si	% P	% S	% Al	% Ti	% B	% N
1	0.163	0.484	0.249	0.017	0.020	0.013	0.041	<0.0001	0.0092
2	0.150	0.473	0.247	0.016	0.019	0.004	0.035	0.0015	0.0116
3	0.156	0.458	0.238	0.017	0.020	0.002	0.024	0.0026	0.0115

Heat treatment interval of AISI 1022 steel is between 830 and 900 0C. For this reason, the temperature of heat treatment for AISI 1022 steel was determined as 875 0C and holding period in this temperature was determined according to the thickness of specimens. The specimens of AISI 1022 without boron and with 15 and 26 ppm boron were kept in the furnace for 60 minutes at 8750C in the Laboratories of Metal Education Department of Technical Education Faculty of Gazi University and then were exposed to two kinds of heat treatment as cooling in the air and water. In the Laboratories of Metal Education Department of Technical Education Faculty of Gazi University, the microstructures of specimens cooled in the air and water were determined via optic microscope and their hardness values were established according to Vickers hardness method. Each sample was subject to 6 hardness tests in order to determine the hardness values and average of these tests was accepted as the result.

3. Results and Discussion

3.1 Microstructure results after heat treatment and discussion

AISI 1022 steel without boron and with 15 and 26 ppm boron was kept in the furnace for 60 minutes at 8750C and then cooled in the air and water. The microstructures of the specimens cooled in the air and water were analyzed. Figure 1a illustrated the microstructure image of the material without boron cooled in the air. In the microstructure images of the material without boron cooled in the air, it is observed that ferrite grains are equiaxed and are surrounded by pearlite islets in some places. The microstructure images of the specimen without boron cooled in the air illustrate polygonal TiN and spherical particles shown with the arrows.

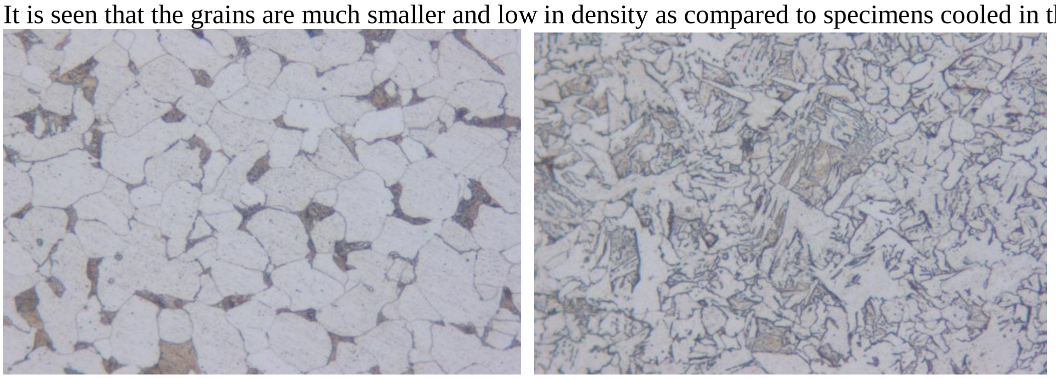


a)
b)

Figure 1. Microstructure images of AISI 1022 steel without boron cooled in a) air and b) water (X500)

The microstructure images of the water-cooled material without boron is presented in Figure 1b. It is seen from these images that the structure shown with arrow is the lath type martensite while the white structure is widmanstatten ferrite.

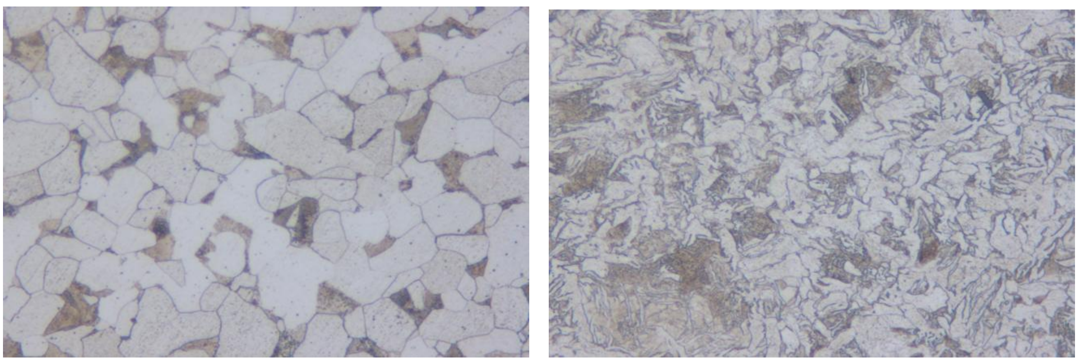
Microstructure images of air-cooled AISI 1022 steel with 15 ppm boron and water-cooled AISI 1022 steel with 15 ppm boron are illustrated in Figure 2a and Figure 2b, respectively. Microstructure images of the air-cooled material without boron demonstrate that grains are equiaxed while microstructure images of the water-cooled material with 15 ppm boron prove existence of lath type martensite and widmanstatten ferrite. It is seen that the grains are much smaller and low in density as compared to specimens cooled in the air.



a) b)

Figure 2. Microstructure images of AISI 1022 steel with 15 ppm boron cooled in a) air and b) water (X500)

The microstructure image of the air-cooled material with 26 ppm boron is seen in Figure 3a and the microstructure image of the water-cooled material with 26 ppm boron is presented in Figure 3b.



a) b)

Figure 3. Microstructure images of AISI 1022 steel with 26 ppm boron cooled in a) air and b) water (X500)

As for the materials without boron and with 15 ppm boron, the materials with 26 ppm boron also have equiaxed grains and there are spherical spots and orange polygonal TiN if cooled in the air. From the microstructure images of the water-cooled materials with 26 ppm boron, lath type martensite and widmanstatten ferrite are observed as done in microstructure images of the materials without boron and with 15 ppm boron. As a result of the heat treatment conducted on AISI 1022 steel with 15 and 26 ppm boron or without boron, it was determined that the specimens cooled in the air have similar grain sizes and the same ASTM number.

3.2 Hardness test results after heat treatment and discussion

The specimens of air- and water-cooled AISI 1022 steel without boron and with 15 and 26 ppm boron were exposed to Vickers hardness measurements as vertical and parallel to rolling direction. Table 2 shows the hardness values of water-cooled AISI 1022 specimens containing boron at different ratio as vertical or parallel to rolling direction.

Table 2. Vickers hardness test results of water-cooled AISI 1022 steel containing boron at different ratios

Material No	Vertical to Rolling Direction (HV 5)	Parallel to Rolling Direction (HV 5)	Boron Ratios (ppm)
1	142	150	No Boron
2	157	159	15
3	160	153	26

Table 3 illustrates the hardness values of air-cooled AISI 1022 steel without boron and with 15 and 26 ppm boron as vertical or parallel to rolling direction.

Table 3. Vickers hardness test results of air-cooled AISI 1022 steel containing boron at different ratios

Material No	Vertical to Rolling Direction (HV 5)	Parallel to Rolling Direction (HV 5)	Boron Ratios (ppm)
1	117	122	No Boron
2	119	120	15
3	121	126	26

Figure 4 illustrates Vickers hardness values of air- and water-cooled specimens as vertical to rolling direction in graphic.

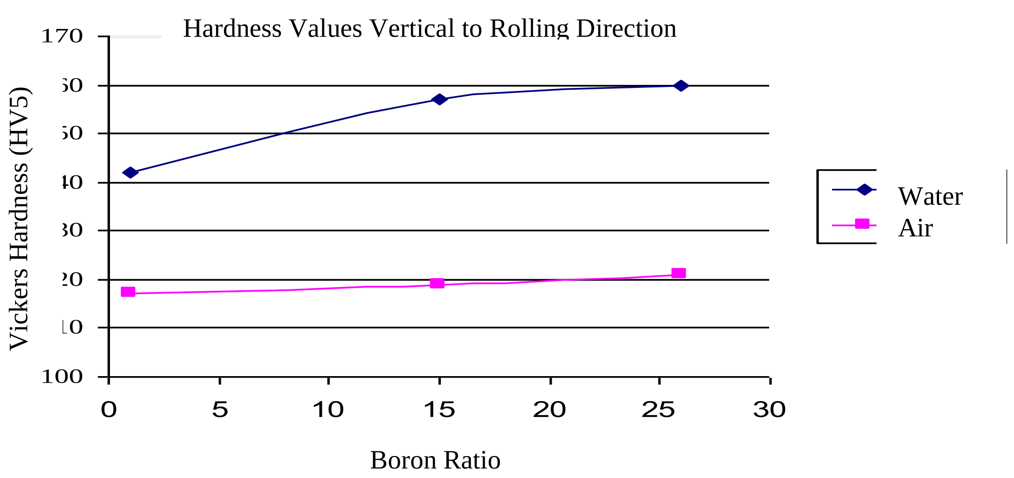


Figure 4. Hardness values of air- and water-cooled AISI 1022 material obtained as vertical to rolling direction

While the hardness value of the specimen without boron in water-cooled AISI 1022 material vertical to rolling direction was 142 HV5, this value increased to 160 HV5 in water-cooled material with 26 ppm boron content. It was observed that there is approximately 18 HV5 increase. An increase in the hardness value with boron ratios between 15 and 20 ppm which is the optimum value in the literature was found.

While the hardness value of the specimen without boron in air-cooled AISI 1022 material vertical to rolling direction was 117 HV5, this value increased to 121 HV5 in water-cooled materials with 26 ppm boron. Approximately 4 HV5 increase was observed. When it is considered that this increase might be within the margin of error, the increase in hardness values as vertical to rolling direction in air-cooled AISI 1022 material is not deemed significant.

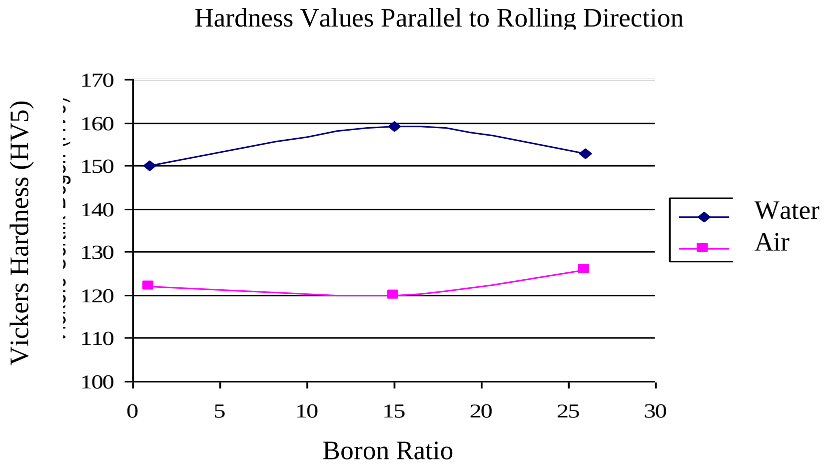


Figure 5. Hardness values of air- and water-cooled AISI 1022 material obtained as parallel to rolling direction

Figure 5 represents Vickers hardness values of water- and air-cooled specimens as parallel to rolling direction in graphic. The hardness value of the specimen without boron in water-cooled AISI 1022 material as parallel to rolling direction increased to 150 HV5 and the hardness value of the material with 15 ppm boron increased to 159 HV5 while this value reduced to 153 HV5 in water-cooled material with 26 ppm boron. Approximately 9 HV5 increase was determined in hardness value. This was found to be higher (18 HV5) in Vickers hardness values in vertical to rolling direction cooled in water. As a result of the examination of hardness values as vertical and parallel to rolling direction of specimens cooled in water, it was observed that there is an increase in hardness values as a result of fast cooling in optimum values of 15 and 20 ppm reported in the literature. It is thought to be a result of boron's remaining as solid melt within the microstructure at the end of this fast cooling.

Llewellyn, D.T. et al. [10] examined SAE 8600, one of the hot treated low alloyed steels with addition of boron, and observed an increase in hardness values in 10 and 20 ppm boron ratios as a result of fast cooling. When boron is cooled down fast (quenching fast) and kept as solid melt within the grain, it provides the greatest effect on hardening [5].

The hardness value of the material without boron in air-cooled AISI 1022 material as parallel to rolling direction was 120 HV5 while the hardness value reduced to 120 HV5 in the material with 15 ppm boron and increased to 126 HV5 in water-cooled material with 26 ppm boron. Approximately 2 HV5 decrease was established in hardness value and this was regarded as margin of error. Upon examination of the Vickers hardness values of air-cooled AISI 1022 steel containing boron at different ratios as vertical and parallel to rolling direction, it was observed that boron ratio wasn't effective.

4. Conclusions

Rolled AISI 1022 material without boron and with 15 and 26 ppm boron was kept for 1 hour at 8750C and then exposed to heat treatment after being cooled down in air and water. It was observed that while lath martensite and widmannstaten ferrite were seen in all of the specimens cooled in water, air-cooled specimens have equiaxed ferrite grains and perlite structure.

Hardness values as vertical and parallel to rolling direction of water-cooled specimens were examined and it was observed that there is an increase in hardness values as a result of fast cooling in optimum values of 15 and 20 ppm reported in the literature. The reason behind this is boron's remaining as solid melt within the microstructure as a result of this fast cooling. When the Vickers hardness values of air-cooled AISI 1022 steel containing boron at different ratios as vertical and parallel to rolling direction were examined, it was observed that boron ratios didn't have a significant effect in respect of hardness.

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