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THE INFLUENCE OF BORON ADDITION ON MICROSTRUCTURE OF LOW-CARBON STEEL SAE 1006

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ABSTRACT

Many researches are done for finding various ways of improving steel properties, since it's the most used material in the world. Instead of using high-alloyed steels, which are expensive, microalloying of carbon steels that will retain equal properties is an efficient replacement.

For this research it was tested melts of low-carbon steel grade SAE 1006 produced via basic oxygen furnace in company ArcelorMittal Zenica. Secondary treatment was done via ladle furnace, where to liquid steel was added the microalloying element boron in the form of FeB wire.

The results showed that the microstructure of all melts was ferritic with the content of pearlite in traces. Pearlite content was lower in the melts with boron. It also showed that boron addition caused growth of ferritic grain.

1. INTRODUCTION

In the modern steelmaking technology there are strict requirements for steel quality mostly about impurities and undesirable elements. Therefore, these requirements led to development of secondary metallurgy also known as ladle metallurgy. The aim of ladle metallurgy is the transfer of some metallurgical processes from primary aggregates to the ladle in order to improve productivity and quality of steel. This include vacuuming, reheating, deep desulphurisation and decarburisation and fine chemical adjustment of fine alloying elements.

The boron is one of the microalloying elements which can improve steel properties when it's added to steel even in small amounts. It can have impact on steel properties in various ways depending on its amount, precipitation form, positioning in the crystal lattice of iron and the type of steel.

With an addition of only 0.001- 0.003% soluble boron to a suitably protected base steel, the hardenability of the steel can be improved to a level comparable to that obtained by additions of about 0.5% Mn, Cr or Mo [1].

Increasing hardenability is the main reason of adding boron to steel and the other benefits of using boron are still investigating.

2. EXPERIMENTAL WORK

The production of three melts of SAE 1006 low-carbon steel and three melts of SAE 1006 steel with boron addition, marked as SAE 1006+B was monitored for this research. Both steel grades were produced via BOF basic oxygen furnace which is shown in the Figure 2.1. The BOF converter is charged with steel or iron scrap (25 - 35%) and the rest is pig iron from blast furnace.

Figure 2.1. Basic oxygen furnace in the company ArcelorMittal Zenica

In the Table 2.1. and Table 2.2. are given the nominal chemical compositions of SAE 1006 and SAE 1006+B based on standard ASTM A 510M.

Table 2.1. The nominal chemical composition of SAE 1006 (% mass) [2]

C	Mn	Si	P	S	C_{eq}
max 0.08	0.25-0.40	-	max 0.040	max 0.050	0.2

Table 2.2. The nominal chemical composition of SAE 1006+B (% mass) [2]

C	Mn	Si	P	S	B
max 0.05	0.25-0.35	max 0.1	max 0.030	max 0.025	0.007-0.01

After the production at converter, melts were subjected to the secondary treatment. Secondary treatment was done via ladle furnace which is presented in the Figure 2.2. Primary deoxidation was done in the ladle during the pouring, by adding deoxidation materials like FeSi and Al.

Figure 2.2. Ladle furnace

CaSi wire is injected into metal bath by wire-feeding method. The main reason for adding this type of wire to steel is a great benefit of calcium for modification of nonmetallic inclusions. Calcium is reacting with sulphur and creating CaS inclusions, instead of MnS inclusions which are harmful in steel. Also, solid aluminates and silico-aluminates that cause clogging of nozzles are transformed into liquid Ca-aluminates at casting temperature.

The production of both steel grades was the same until the stage of secondary tretament. In this stage, FeB wire was injected into metal bath via wire-feeding method in case of the melts with boron addition. In the Table 2.3. is given the chemical composition of CaSi and FeB wires. The diameter of both wires was φ 13 mm. The amount of boron in FeB wire was 17.49 %.

Table 2.3. Chemical composition of wires for injection [2]

Type of wire	*Chemical composition [% mass]*						
	Si	**Ca**	**C**	**B**	**Fe**	**Al**	**S**
CaSi	59.95	29.29	0.72	/	8.77	1.25	0.02
FeB	/	/	0.22	17.49	82.236	0.054	/

Before injecting the FeB wire there are few requests that has to be acomplished: steel has to be well deoxidated, slag has to be removed from the surface of metal bath, stirring with argon has to be minimal.

The most important thing while injecting the wires is wire feed speed, and it has to be high to ensure the best yield of wire. By adding 145 meters of FeB wire the aimed boron content in steel is achieved.

In the Table 2.4. is given the final chemical composition of all tested melts. It can be seen that all the results are in the range of the nominal values.

Table 2.4. The final chemical composition of tested melts [3]

Grade	**Melt**	*Chemical composition [% mass]*											
		C	**Si**	**Mn**	**P**	**S**	**Cu**	**Cr**	**Ni**	**Al**	**Ca**	**N**	**B**
SAE 1006	HA	0.05	0.05	0.30	0.011	0.013	0.06	0.01	0.04	0.005	0.1	0.07	/
	HB	0.05	0.04	0.30	0.023	0.020	0.07	0.01	0.04	0.004	0.09	0.06	/

	HC	0.05	0.06	0.33	0.020	0.016	0.06	0.01	0.04	0.003	0.05	0.06	/
SAE 1006+B	HX	0.04	0.06	0.33	0.022	0.018	0.09	0.02	0.05	0.002	0.11	0.07	0.01
	HY	0.04	0.05	0.30	0.024	0.013	0.07	0.02	0.04	0.004	0.06	0.06	0.01
	HZ	0.04	0.07	0.30	0.012	0.007	0.07	0.02	0.04	0.004	0.21	0.07	0.009

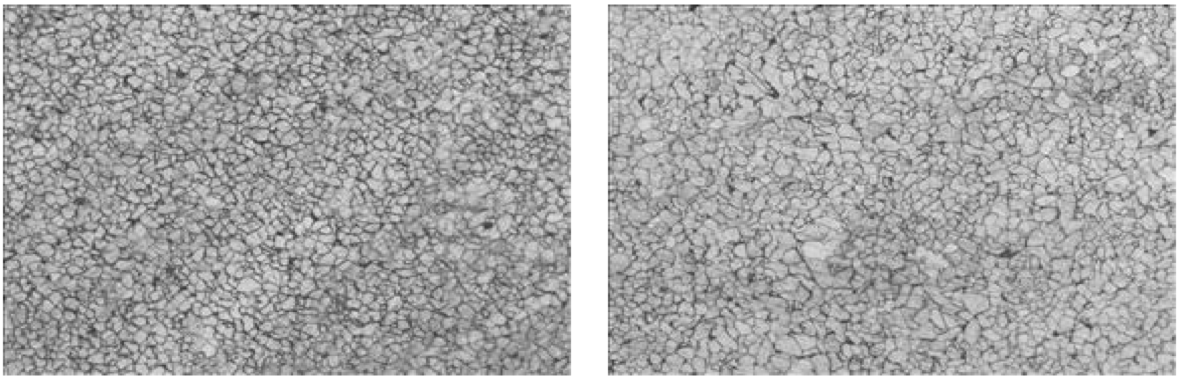
After secondary treatment steel is continuously cast into billets with dimensions of 120x120 mm. Billets were further plastic deformed at wire mill. The final product made from these steel grades was hot-rolled wire of φ 5.5 mm.

Samples of wire from different coils were taken and examined in the metalographic laboratory, where was noticed the influence of boron addition on the microstructure of low-carbon steel grade SAE 1006.

3. RESULTS AND DISCUSSION

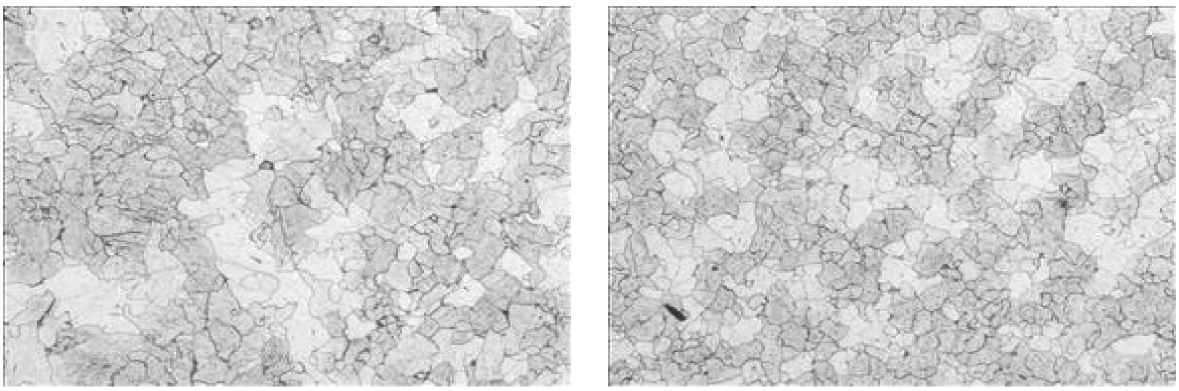
For the testing of microstructure and grain size were taken samples of three melts for each steel grade. For each melt were taken samples of four different coils.

In the Figure 3.1. is shown the microstructure of two different coils from HC melt of SAE 1006. The Figure 3.2. presents the microstructure of two different coils from HZ melt of SAE 1006+B. The microstructure of both steel grades was ferritic with low content of pearlite (< 1 %). After boron addition the amount of pearlite is decreased.



a) Coil 1 b) Coil 2

Figure 3.1. The microstructure of HC – grade SAE 1006, magnification x100



a) Coil 1 b) Coil 2

Figure 3.2. The microstructure of HZ – grade SAE 1006+B, magnification x100

The grain size is determined by specialy made software which is connected to the optical microscope. Software is called *LAS V3.7* standard ISO 643:2003, method of horizontal lines. Grain size is determined while the magnification of sample is 100x.

In the Figure 3.3. is presented the marking way of sample for determining the grain size. The program automatically counts grains and sorts them in groups by size. The amount of counted grains by their size is given in the histogram of grain number. In the Figure 3.4. is shown the histogram of grain number for melt HB of SAE 1006 steel grade.

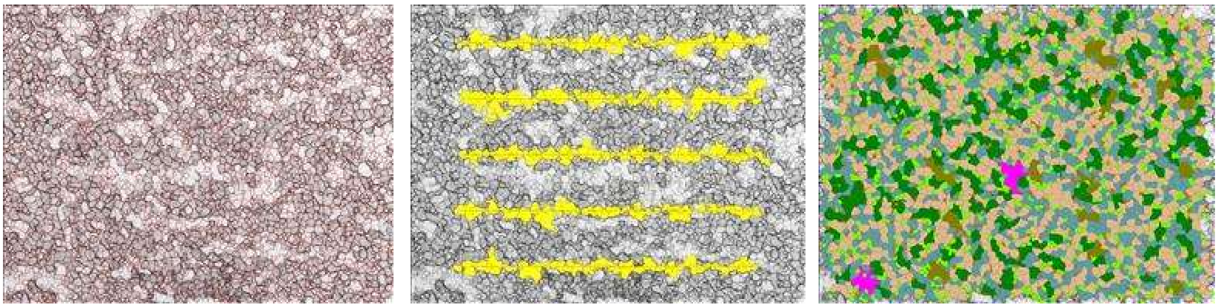


Figure 3.3. Marking the sample for determination of grain size for HB- SAE 1006[3]

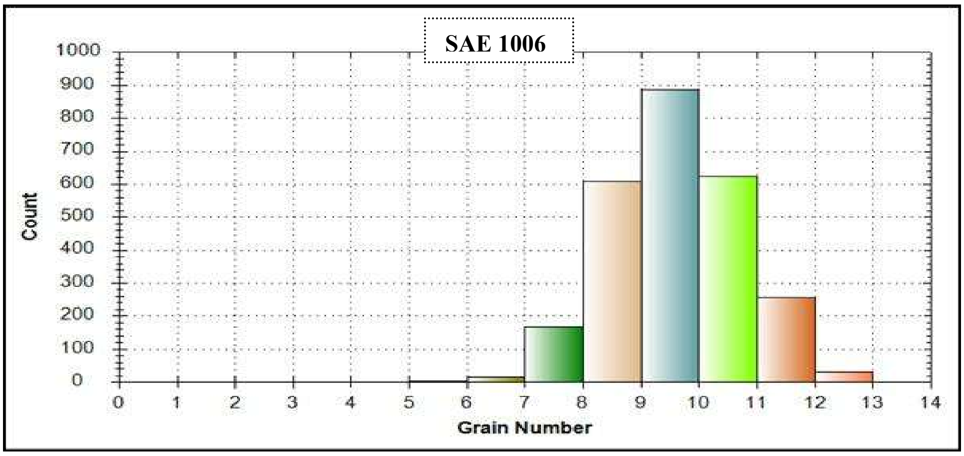


Figure 3.4. The histogram of grain number for HB – SAE 1006 [3]

In the Table 3.1. is presented the average grain number of tested melts for grade SAE 1006. In the Table 3.2. is presented the average grain number of tested melts for grade SAE 1006+B, i.e. with boron addition.

Table 3.1. Grain number for grade SAE 1006 [3]

Melt	Average grain number by melts	Average grain number of grade
Melt A	8.83000	8.921
Melt B	8.96025	
Melt C	8.97275	

Table 3.2. Grain number for grade SAE 1006+B [3]

Melt	Average grain number by melts	Average grain number of grade
Melt X	7.3715	7.075
Melt Y	6.6190	
Melt Z	7.2345	

On the histogram in the Figure 3.5. is shown the comparation of grain size for tested grades. The average grain number of steel without boron addition is 8.921 which is approximately 16 µm of grain size. The average grain number after boron addition is 7.075 which is approximately 30 µm of grain size.

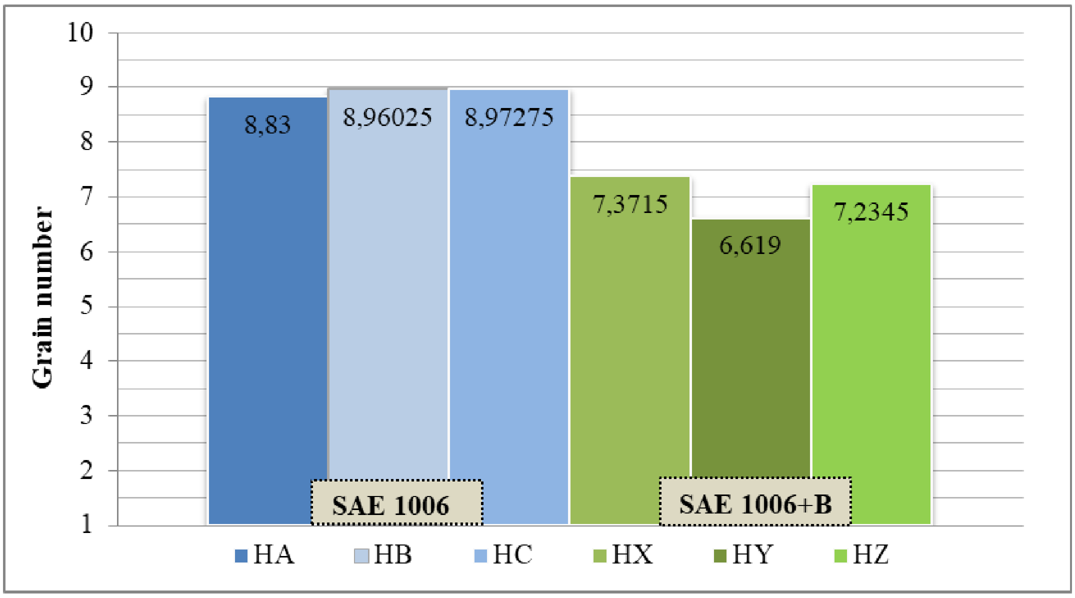
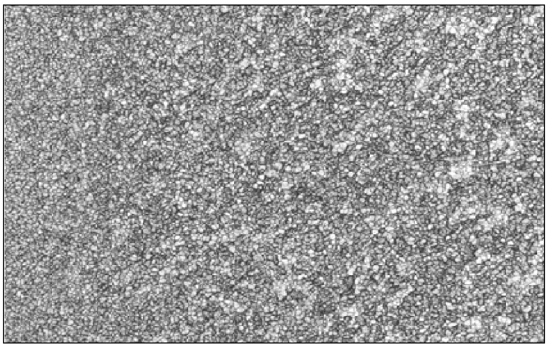
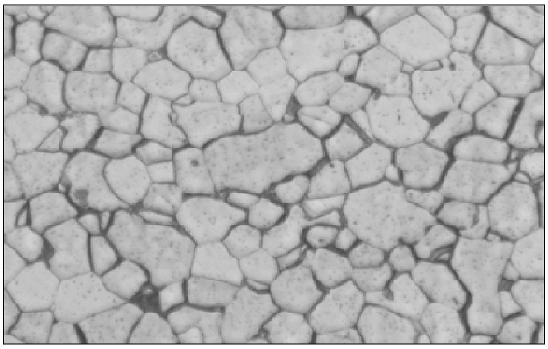


Figure 3.5. Comparation of grain size for SAE 1006 and SAE 1006+B

In the Figure 3.6. and 3.7. are shown the microstructures of steel SAE 1006 with and without boron addition. From these microstructures can be noticed an obvious difference in grain size.

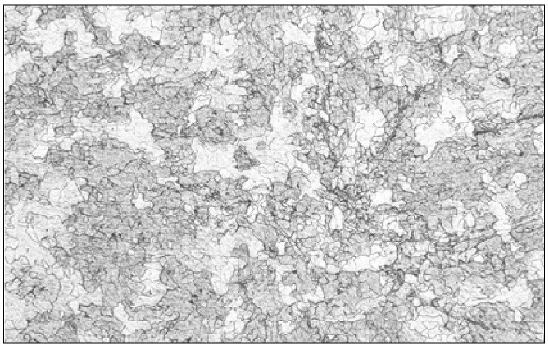


a) *Magnification* x50

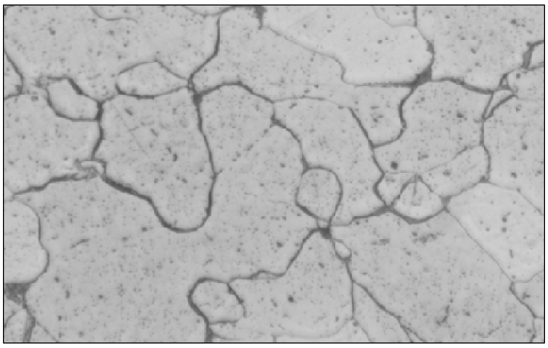


b) *Magnification* x500

Figure 3.6. The microstructure of HB - SAE 1006



a) *Magnification* x50



b) *Magnification* x500

Figure 3.7. The microstructure of HY - SAE 1006+B

According to [4] the reason for coarse ferrite grain in boron-added steel can be attributed to the presence of coarse boron nitride (BN) as nucleating site instead of fine aluminium nitride (AlN) in steel without boron. Both boron and nitrogen have higher diffusion rate than that of aluminium in the austenite matrix during temperatures above 1200 °C, precipitation of BN tends to precede the formation of AlN when hot rolled steel sheets are air cooled after hot rolling deformation. The increased ferritic grain is particularly significant for the further processing of hot-rolled wire by cold drawing.

4. CONCLUSION

The production of SAE 1006 steel grade included the production via basic oxygen furnace, primary deoxidation and secondary treatment via ladle furnace.

The boron addition had influence on the microstructure of steel. It was manifested through the change of ferritic grain size and the amount of pearlite.

The boron addition in the range from 0.007 % to 0.01 % increased the size of ferritic grain and decreased the amount of pearlite in microstructure of three tested melts.

The average grain number of tested SAE 1006 steel grade was 8.921 matching grain size of approximately 16 μm, and the average grain number of tested SAE 1006 steel with boron addition was 7.075 matching grain size of approximately 30 μm.

The increased ferritic grain is particularly significant for the further processing of hot-rolled wire by cold drawing.

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