



RESEARCH ARTICLE

THE INFLUENCE OF MICROALLOYING WITH BORON ON PROPERTIES OF AUSTENITE STAINLESS STEEL X8CrNiS18-9

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Abstract

More recently a modified stainless steels have been used to produce various structural elements that work in complex operating conditions. Stainless steel X8CrNiS18-9 (standard EN 10088-3: 2005) is the most commonly used austenitic stainless steel due to its good machinability. This steel has high mechanical and working properties thanks to a complex alloying, primarily with the elements such as chromium and nickel. The content of sulphur present in the steel from 0.15 to 0.35% improves machinability. However, while sulphur improves machinability at the same time decreases the mechanical properties particularly toughness. The addition of sulphur, which is the cheapest available additive for free machining, will impair not only the transverse strength and toughness, but also the corrosion resistance. The aim of this work is to determine the influence of microalloying with boron on the machinability, corrosion resistance and mechanical properties the mentioned steel, but also to determine the effect of microalloying with boron on above steel, which is already microalloyed with zirconium, tellurium, or both elements (zirconium and tellurium) due to modification of non-metallic inclusions and improvement of properties.

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Introduction:-

Boron in austenitic stainless steels enables precipitation hardening (increase in conventional yield strength and tensile strength), but reduces the resistance to general corrosion [1].

Boron is used as an alloying element in many materials, and in steel it is most commonly used as an alloying element because of its effect on increasing hardenability. The addition of boron up to 0.01% in austenitic steels improves their high temperature strength. Boron-containing steels used as high-quality construction steels intended for heat treatment, hardening steels and steels for cold processing such as steels for bolts [2].

Boron is also used in the austenitic stainless steel for the control of hot cracks, or to improve their creep characteristics. Boron is an interstitial element and has a very low solubility in α -solid solution (<0.003%). For this reason, the actual content of boron in construction steels usually does not exceed 0.002 to 0.005%. Higher amounts of boron result in the formation of boride eutectic which lowers the toughness and strength of steel during hot processing at various temperatures [3].

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In steel, boron can be dispersed in a matrix in the form of Fe_2B , boride with a size of $20\text{-}30 \times 10^{-8}$ cm, and free which mainly segregates surrounding the primary boundaries of the austenite grain. This small amount of soluble boron distributed along the grain boundary obviously slows down the γ - α transformation by diffusion, or prevents a ferrite reaction that increases the hardness of the steel [4].

Boron is considered as another possible element which improves the ductility at hot processing with similar types of steel. At relatively low temperatures, where austenitic and ferrite phases coexist, boron is thought to have a beneficial effect due to the precipitation of $\text{Fe}_{23}(\text{B}, \text{C})_6$ in the matrix. These precipitates act as preferential sites for intragranular nucleation of ferrite. In this way a smaller amount of ferrite is formed at the grain boundaries. This not only reduces the number of empty spaces and cavities formed at the grain boundaries, but also makes the interior of the austenitic grains more deformable due to the soft intragranular ferrite. The final result is an improvement in ductility in hot processing [5].

Experimental Research and Test Results

The melting and casting of austenitic stainless steel X8CrNiS18-9 was carried out in a vacuum induction furnace with a capacity of 20 kg, with a maximum power of 40 kW, and is located at the Department for melting and metal casting of the Institute "Kemal Kapetanović". Eight meltings were done. This means that we will, in addition to the melt without alloying elements and melt microalloyed with boron, produce six more melts and that microalloyed with zirconium, tellurium and zirconium and tellurium, after which we will also add boron to these variants. The ingots were processed by forging, hot rolling and heat treatment.

In preliminary research is planned that after primary processing (approx $\phi 50$ mm) samples will be tested by cutting forces, in order to determine to what extent the modification of the chemical composition affects the machinability of this material, and corrosion resistance. Of particular importance is to determine the behavior of nonmetallic inclusions in the process of developing structural parts and in a later exploitation. For this reason it is planned to simulation processing of austenitic stainless steel by plastic processing and by forging and rolling with two different degrees of processing. After that, the samples will be taken and laboratory testing of mechanical properties will be performed. Chemical analysis of the eight melt variants are given in Table 1.

Table 1:- Chemical analysis of melt variants [6].

Melt variants	Chemical composition (%)									
	C	Si	Mn	P	S	Cr	Ni	B	Zr	Te
Without alloying elements	0,03	0,42	0,61	0,021	0,18	18,3	9,4	–	–	–
Alloyed with B	0,05	0,47	0,66	0,021	0,19	18,5	9,5	0,004	–	–
Alloyed with Zr	0,04	0,35	0,75	0,021	0,17	18,8	9,4	–	0,016	–
Alloyed with B and Zr	0,04	0,49	0,69	0,012	0,17	18,5	9,1	0,004	0,009	–
Alloyed with Te	0,05	0,40	0,80	0,010	0,16	18,9	9,3	–	–	0,033
Alloyed with B and Te	0,04	0,35	0,78	0,011	0,18	18,8	9,3	0,004	–	0,039
Alloyed with Zr and Te	0,03	0,47	0,72	0,012	0,18	18,5	8,9	–	0,007	0,040
Alloyed with B, Zr and Te	0,04	0,44	0,78	0,012	0,19	17,1	9,3	0,006	0,012	0,042

Machinability

In the Laboratory for metal cutting and machine tools of the Faculty of Mechanical Engineering in Zenica, the machinability test of the ingots was done, based on the estimation of parameters of the cutting force. Testing on both samples was performed under the same treatment regime. The results of the cutting force tests (individual forces F_x , F_y , and F_z as well as the resultant force F_R) are given in Table 2.

The melt microalloyed with boron, and even melt microalloyed with boron and zirconium have better machinability compared to the melts without alloying elements and melt microalloyed with only zirconium, respectively. However, this is not the case for the melts microalloyed with tellurium. Melts microalloyed with tellurium and zirconium and tellurium have significantly better machinability compared to those microalloyed with boron and tellurium, and boron, zirconium and tellurium, respectively.

Table 2:- The results of the cutting force tests [6].

Melt variants	Cutting force (N)			The resultant force F_R (N)
	Component F_x	Component F_y	Component F_z	
Without alloying elements	180	218	361	458,52
Alloyed with B	166	195	350	433,68
Alloyed with Zr	193	235	362	472,77
Alloyed with B and Zr	173	209	353	445,21
Alloyed with Te	154	200	317	405,22
Alloyed with B and Te	223	247	469	575,06
Alloyed with Zr and Te	137	164	289	359,42
Alloyed with B, Zr and Te	165	206	342	432,00

Corrosion Resistance

General corrosion tests for X8CrNiS18-9 stainless steel samples were performed on a potentiostat / galvanostat PAR 263A-2 device in an electrochemical cell prescribed by ASTM G5-94. The samples were tested in a solution of 1% HCl at room temperature. The solution was previously deaerated with argon for 30 minutes as provided by ASTM G5-94. To test the general corrosion of the X8CrNiS18-9 stainless steel samples, the Tafel Directional Extrapolation Method described by ASTM G3-89 was used. The results of testing the general corrosion rate of these samples are given in Table 3.

Table 3:- Test results for general corrosion rate [6].

Melt variants	Corrosion current I_{Corr} (μA)	Corrosion rate v_{Corr} (mm/year)	Open circuit potential $E_{(I=0)}$ (mV)
Without alloying elements	4,266	4,955	-475,320
Alloyed with B	3,138	3,645	-472,042
Alloyed with Zr	3,175	3,687	-474,438
Alloyed with B and Zr	1,862	2,163	-468,448
Alloyed with Te	8,949	10,390	-504,517
Alloyed with B and Te	2,349	2,728	-473,578
Alloyed with Zr and Te	3,523	4,092	-472,957
Alloyed with B, Zr and Te	2,686	3,119	-474,366

Melts microalloyed with boron, boron and zirconium, boron and tellurium, and boron, zirconium and tellurium have lower corrosion rate of the melt without the alloying elements, and the melts microalloyed with zirconium, tellurium, or tellurium and zirconium, respectively. Particularly significant is the reduction in corrosion rate for melt microalloyed with tellurium from 10.390 to 2.728 mm/year for the melt microalloyed with boron and tellurium.

Mechanical Properties

After the rolling process was completed, specimens were prepared for mechanical testing (tensile properties and impact toughness testing). The tests were performed at the Mechanical Laboratory of the Institute "Kemal Kapetanović" in Zenica. The results of the tensile properties and impact toughness testing are given in Table 4.

The impact toughness value is even slightly higher for melts microalloyed with boron and zirconium, and boron and tellurium compared to those microalloyed with zirconium, and with tellurium, respectively.

Table 4:- Test results of tensile properties and impact toughness in rolled condition [6].

Melt variants	Conventional yield strength $R_{p0.2}$ (N/mm ²)	Tensile strength R_m (N/mm ²)	Elongation A (%)	Reduction Z (%)	Impact toughness (J) KV 300 J	
					Individually	Average
Without alloying elements	349	670	50,0	70	60; 56; 56	57

Alloyed with B	380	661	43,0	60	48; 47; 59	51
Alloyed with Zr	321	653	51,5	63	55; 69; 55	60
Alloyed with B and Zr	356	653	45,5	57	68; 69; 59	65
Alloyed with Te	314	635	46,5	59	58; 69; 60	62
Alloyed with B and Te	296	631	53,5	61	75; 57; 71	68
Alloyed with Zr and Te	312	629	47,5	53	64; 69; 62	65
Alloyed with B, Zr and Te	338	632	49,5	62	57; 57; 63	59

Metallographic Testing of Rolled Samples

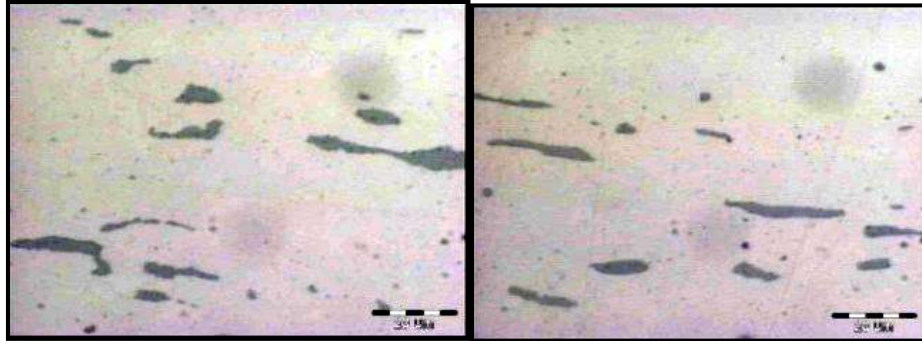
Upon completion of the second stage of deformation (rolling to dimensions 14 x 50 mm), samples were taken to perform metallographic testing for the rolling condition. BAS EN 10088-1 does not specify limit values for the content of nonmetallic inclusions. The content, size and distribution of nonmetallic inclusions in the unetched state were analyzed, and the test results are given in Table 5.

Table 5:- Results of metallographic testing of rolled samples [6].

Melt variants	Sulphides		Note
	Thin	Thick	
without alloying elements	3	1,5	Many small sulphide inclusions with thickness less than 2µm have been observed. A complex inclusion of 250 µm size was also observed.
alloyed with B	3	1	Many small sulphide inclusions with thickness less than 2µm have been observed.
alloyed with Zr	3	3	Many small sulphide inclusions with thickness less than 2µm have been observed. A complex oxysulfide inclusion of 500 µm size was also observed.
alloyed with B i Zr	1,5	3	Many small sulphide inclusions with thickness less than 2µm have been observed. Complex inclusions of size 600, 300 µm were also observed.
alloyed with Te	3	3	Many small sulphide inclusions with thickness less than 2µm have been observed. Complex inclusions of size 600, 500, 300, 200 µm were also observed.
alloyed with B i Te	1,5	1	Many small sulphide inclusions with thickness less than 2µm have been observed. A complex inclusion of 150 µm size was also observed.
alloyed with Zr i Te	1,5	3	Many small sulphide inclusions with thickness less than 2µm have been observed. Complex inclusions of size 600, 150, 60 µm were also observed.
alloyed with B, Zr i Te	1,5	3	Many small sulphide inclusions with thickness less than 2µm have been observed. Complex inclusions of size 500 µm were also observed.

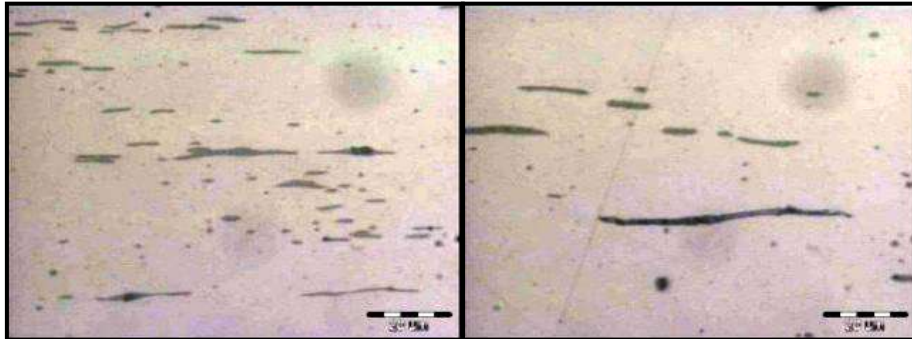
The test for the rolling condition was performed in accordance with Standard Test Methods for Determining the Contents of Inclusions in Steel – ASTM E45-11. In experimental melts after rolling and after heat treatment, the presence of type A inclusions (sulphides) according to ASTM E45-11 was detected. The largest number of inclusions and the biggest inclusions were determined for tellurium alloyed melt, and for variants of melts alloyed with boron and zirconium and zirconium and tellurium elements.

Sample imaging under a certain magnification (x50) was performed on an OLYMPUS PMG3 type optical microscope, and one image was given for each sample (Figure 1).



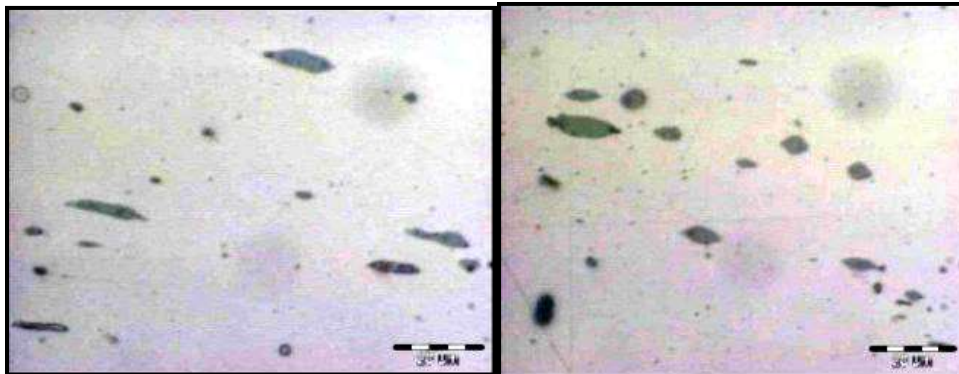
a) without alloying elements

b) alloyed with B



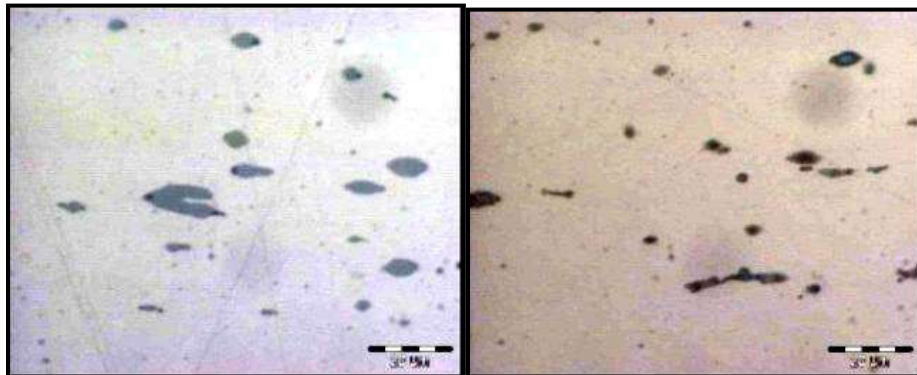
c) alloyed with Zr

d) alloyed with B i Zr



e) alloyed with Te

f) alloyed with B i Te



g) alloyed with Zr i Te

h) alloyed with B, Zr i Te

Figure 1:- Microstructure of all melt variants for rolled state [6].

Conclusions:-

The aim of the research was to examine the influence of the boron on machinability, corrosion resistance and mechanical properties, as well as the content, size and distribution of nonmetallic inclusions in the unetched state of austenitic stainless steel X8CrNiS18-9, with and without alloying with boron, were analyzed. Also, as stated above, the aim of this paper is to determine the effect of microalloying with boron on said steel, which is already microalloyed with zirconium, tellurium or both elements (zirconium and tellurium).

After all the tests performed, it is possible to draw the following conclusions:

1. The effect of boron on machinability is positive and leads to a reduction in the cutting force if no tellurium is present in the melt. In melts in which tellurium is also present, either individually or in combination with zirconium, the addition of boron leads to an increase in the cutting force, which adversely affects machinability.
2. With regard to the effect of microalloying with boron on the corrosion rate of austenitic stainless steel X8CrNiS18-9, it can be concluded that boron reduces the corrosion rate in all variants.
3. All values of tensile properties (conventional yield strength, tensile strength, elongation and reduction) and impact toughness are within the limits prescribed by the relevant standard for the material specified.
4. The influence on the shape and size of the nonmetallic inclusions is especially shown by zirconium and tellurium. Addition of tellurium with zirconium and boron improves the globularization of austenitic stainless steel X8CrNiS18-9, in this respect tellurium is particularly dominant.

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