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INFLUENCE OF BORON, ZIRCONIUM AND TELLURIUM ON THE MECHANICAL PROPERTIES OF AUSTENITIC STAINLESS STEEL

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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 sulfur present in the steel from 0.15 to 0.35% improves machinability. However, while sulfur improves machinability at the same time decreases the mechanical properties particularly toughness.

The aim of this work is to determine the influence of boron, zirconium and tellurium on the mechanical properties the mentioned steel. Change of mechanical properties, depending on the chemical composition of the steel is simulated with MATLAB program.

1. INTRODUCTION

Austenitic stainless steel X8CrNiS18-9 (EN 1.4305) also known as AISI 303 stainless steel has the best machinability of all steels of same kind.

The high content of sulfur or selenium in these steels improves their machinability. For this reason, they are produced only in the form of beams and rods and are used primarily in mass production of screws.

These types of steel are mainly used for less mechanically loaded parts, because their toughness and dynamic durability are weaker than in other structural steels [1].

2. EXPERIMENTAL PRODUCTION AND PROCESSING OF STEEL X8CrNiS18-9

2.1. Melting and casting

In accordance with the program of testing at the Department for melting and metal casting of the Kemal Kapetanovic Institute, eight melts with various contents of boron, zirconium and tellurium were produced. The first melt was produced without the addition of alloying elements, while in the remaining melts the contents of the noted elements were given individually, then in combinations with two alloying elements, and the final melt with all three alloying elements. Melting and casting of austenitic stainless steel X8CrNiS18-9 was carried out in a vacuum induction furnace. Chemical analysis of all melt variants are given in Table 1.

Table 1. Chemical analysis of all melt variants [2]

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	–	–	–
B	0.05	0.47	0.66	0.021	0.19	18.5	9.5	0.004	–	–
Zr	0.04	0.35	0.75	0.021	0.17	18.8	9.4	–	0.016	–
Te	0.05	0.40	0.80	0.010	0.16	18.9	9.3	–	–	0.033
B and Zr	0.04	0.49	0.69	0.012	0.17	18.5	9.1	0.004	0.009	–
B and Te	0.04	0.35	0.78	0.011	0.18	18.8	9.3	0.004	–	0.039
Zr and Te	0.03	0.47	0.72	0.012	0.18	18.5	8.9	–	0.007	0.040
B, Zr and Te	0.04	0.44	0.78	0.012	0.19	17.1	9.3	0.006	0.012	0.042

2.2. Forging

After heat treatment, the samples were subjected to the forging on the press (three times) and the final forging was done on an air hammer approximate to ϕ 50 mm. The mentioned plants are located at the Department for Metal Plastic Processing of the Institute "Kemal Kapetanović".

2.3. Rolling

After forging, the samples were subjected to a new degree of deformation by rolling. Rolling was carried out on the SKET rolling mill (Figure 1), where the first cross-section of the sample was reduced to □18 mm, and after the second passing through a final sample dimensions were □14 x 50 mm. Rolling speed was 400 rpm. Figure 2 shows the all samples after the rolling process have been performed.

Figure 1. SKET rolling mill

Figure 2. Samples after the rolling process

3. MECHANICAL TESTS

After completion of the rolling process, the preparation of the test tubes for mechanical testing was started, and geometry of the test sample is shown in Figure 3. The results of the tensile properties are given in Table 2.

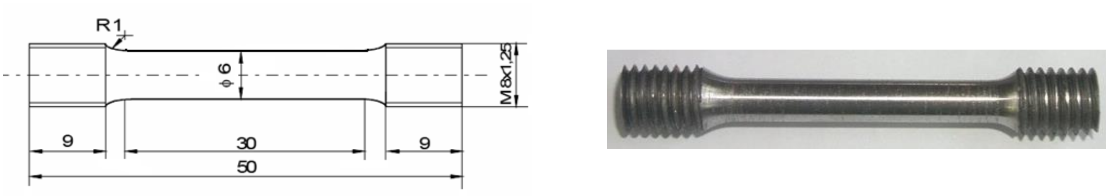

Figure 3. Test tube for determination of tensile properties

Table 2. Test results of tensile properties afterr the rolling process [2]

Melt variants	*Conventional yield strength* $R_{p0,2}$ *(N/mm^2)*	*Tensile strength* R_m *(N/mm^2)*	*Elongation A (%)*	*Reduction Z (%)*
Without alloying elements	349	670	50.0	70
B	380	661	43.0	60
Zr	321	653	51.5	63
Te	314	635	46.5	59
B and Zr	356	653	45.5	57
B and Te	296	631	53.5	61
Zr andTe	312	629	47.5	53
B, Zr and Te	338	632	49.5	62

4. STATISTICAL ANALYSIS OF EXPERIMENTAL RESULTS

In order to obtain a more complete insight into the existence of a connection between the obtained test results and the chemical composition, data processing for the obtained values of mechanical properties (conventional yield strength and tensile strength) was performed using MATLAB 7.0 software package [3]. The analysis was conducted in the way that functional dependency results of mechanical properties with the basic parameters of boron, zirconium and tellurium content were requested.

4.1. Determination of the regression dependence of chemical composition and mechanical properties

4.1.1. Determination of the regression curve for the conventional yield stress ($R_{p0.2}$)

The data for the observed indicators of the influence of the content of alloying elements of boron, zirconium and tellurium on the experimentally determined values of the conventional yield stress and tensile strength are shown in Table 3.

Table 3. Conventional yield stress and tensile strength for different values of alloying elements [2]

Melt variants	**B** (%)	**Zr** (%)	**Te** (%)	$R_{p0.2E}$ (N/mm^2)	R_{mE} (N/mm^2)
Without alloying elements	0	0	0	349	670
B	0.004	0	0	380	661
Zr	0	0.016	0	321	653
Te	0	0	0.033	314	635
B and Zr	0.004	0.009	0	356	653
B and Te	0.004	0	0.039	296	631
Zr and Te	0	0.007	0.04	312	629
B, Zr and Te	0.006	0.012	0.042	338	632

For the data in Table 3, in the MATLAB software package, the regression coefficients were calculated and a stepwise procedure was applied in order to determine the significance of the impact factors and their interactions. In this way, a mathematical model was obtained (1).

$$R_{p0.2M} = 360.1315 + 3044.3869 \cdot B - 2290.7745 \cdot Zr - 1706.3718 \cdot Te + 119546.036 \cdot Zr \cdot Te \quad ...(1)$$

Table 4 gives the statistical characteristics of the given model (1).

Table 4. Statistical characteristics of the conventional yield stress $R_{p0.2M}$ [3]

$R_{p0.2M}$	R^2	S_{ey}	$SS_{reg.}$	$SS_{rez.}$	F_{Mi}	F_{Tabi}	Significance
Condition after rolling	0.922	19.649	4947	386.1	9.612	9.12	DA

From Table 4 it can be seen that the regression shown by expression (1) has a coefficient of determination of $R^2 > 0.922$, and the coefficient of correlation $R > 0.960$.

The adequacy of the model (1) is checked by Fisher criterion with degrees of freedom dfreg = 4, dfrez. = 3 and significance threshold $\alpha = 0.05$. Theoretical, the critical value from the corresponding Tabeleis $R_{p\ 0.2\ (4,3,0.05)} = 9.12$ [4]. Since the calculated value is $F_M = 9.612 > F_{Tab.M} = 9.12$, the mathematical model for the conventional yield stress $R_{p0.2M}$ is adequate.

Subsequent analysis required the functional dependence of the results of the conventional yield stress and the basic parameters of the content of boron, zirconium and tellurium. Since the regression surfaces described in (1) can not be represented in a three-dimensional space, the regression variables are replaced by their average values. 3D models for different values of changing variables in the given interval are presented in Figure 4, for the mean values of the third component.

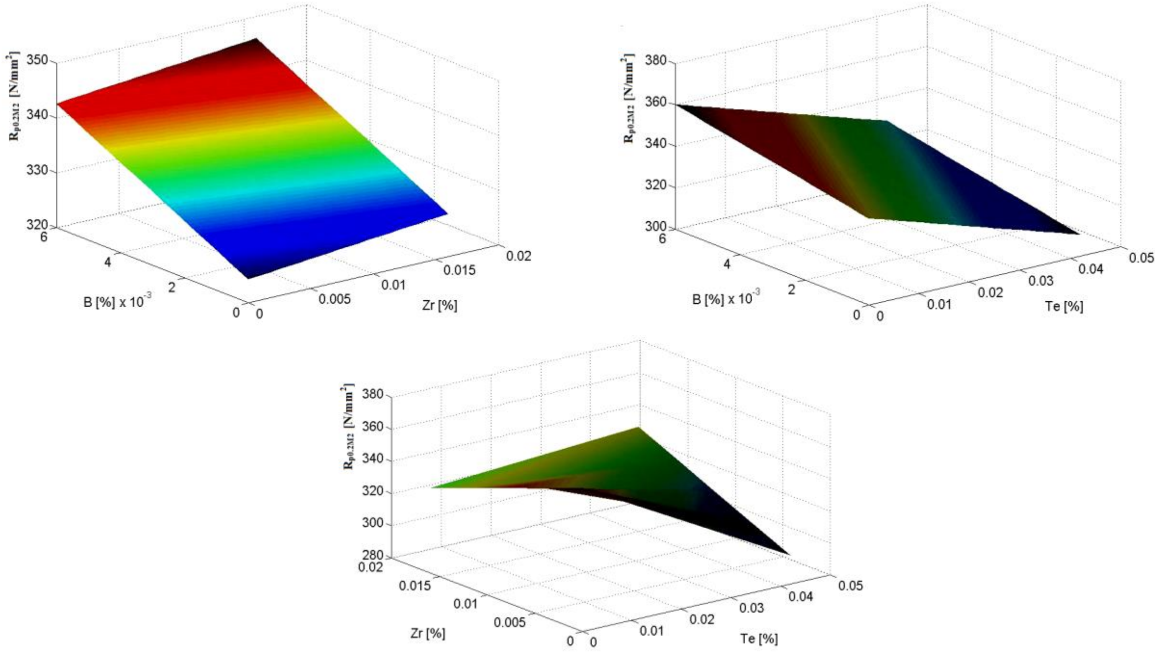

Figure 4. The functional dependence of the yield stress on the content of boron, zirconium and tellurium [2]

4.1.2. Determination of the regression curve for the tensile strength (R_m)

For the data in Table 3, in the MATLAB software package, the regression coefficients were calculated and a stepwise procedure was applied in order to determine the significance of the impact factors and their interactions. In this way, a mathematical model (expression) was obtained (2).

$$R_{mM} = 669.628086 - 2009.79623 \cdot B - 1018.69371 \cdot Zr - 1042.26125 \cdot Te + 63624.7779 \cdot B \cdot Te + 28728.9417 \cdot Zr \cdot Te \quad ...(2)$$

Table 5 gives the statistical characteristics of the given model (2).

Table 5. Statistical characteristics of the tensile strength R_{mM} [3]

R_{mM}	R^2	S_{ey}	$SS_{reg.}$	$SS_{rez.}$	F_{Mi}	F_{Tabi}	Significance
Condition after rolling	0.9994	1.015	1727	1.031	670.289	19.30	DA

From Table 5 it can be seen that the regression shown by expression (2) has a coefficient of determination of $R^2 > 0.9994$, and the coefficient of correlation $R > 0.998$.

The adequacy of the model (2) is checked out by Fisher criterion, where for degrees of freedom $df_{reg} = 5$, $df_{rez.} = 2$ and significance threshold $\alpha = 0.05$. Theoretical, the critical value from the corresponding Tabele is $F_{(5,2,0.05)} = 19.30$ [4]. Since the calculated value is $F_M = 670.289 > F_{Tab.M} = 19.30$, the mathematical model for the tensile strength R_{mM} is adequate.

Subsequent analysis required the functional dependence of the results of the tensile strength with the basic parameters of the content of boron, zirconium and tellurium. Since the regression surfaces described in (2) can not be represented in a three-dimensional space, the regression variables are replaced by their average values. 3D models for different values of changing variables in the given interval are presented in Figure 5, for the mean values of the third component.

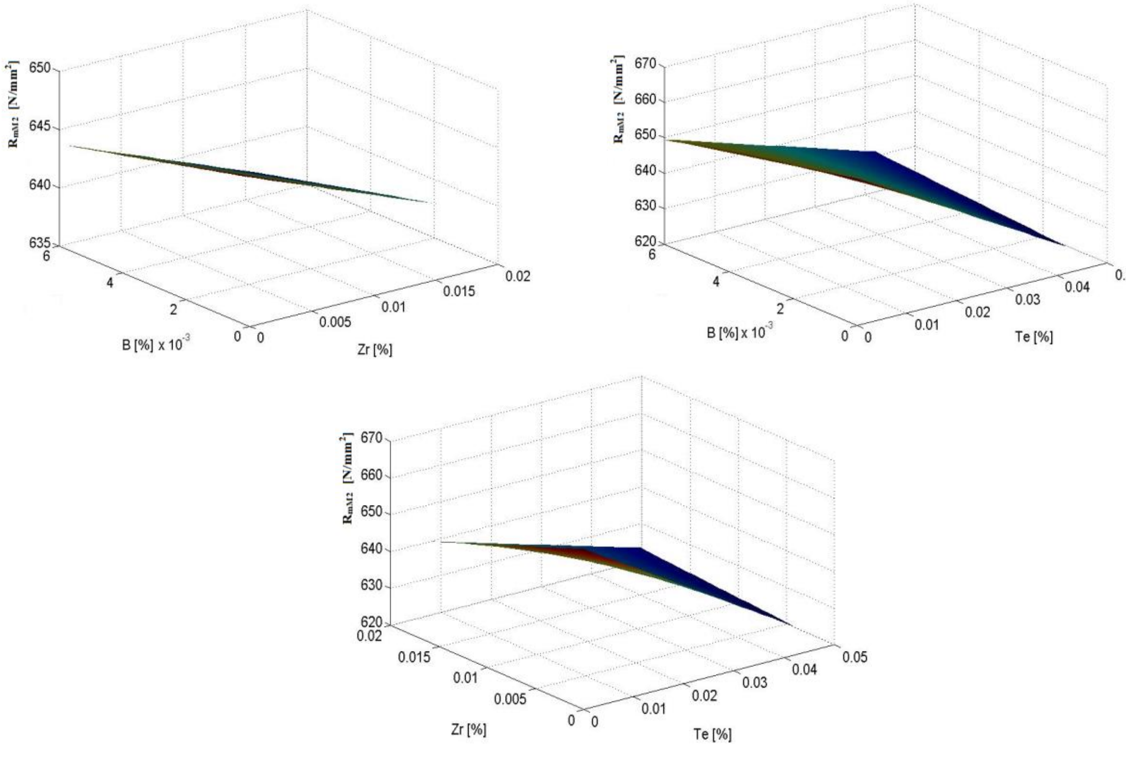

Figure 5. The functional dependence of the tensile strength on the content of boron, zirconium and tellurium [2]

5. CONCLUSIONS

The objective was to determine the influence of boron, zirconium and tellurium, on the mechanical properties of austenitic stainless steel X8CrNiS18-9 with the addition of sulfur.

Conventional yield stress and tensile strength tests were carried out in a rolled condition and the influence of chemical elements boron, zirconium and tellurium on the mechanical properties were monitored.

Based on experimental research, it is possible to make the following conclusions:

- All the values of the tensile characteristics are within the limits prescribed by the appropriate standard, or higher as in the case of elongation value, where even the minimum value of elongation of 43% for the boron-alloyed melt significantly exceeds the value prescribed by the standard of 35% (Table 2).
- Based on the obtained results, it can be concluded that the addition of microalloying elements of boron (0.004 - 0.006%) and zirconium (0.007 - 0.016%) can improve the mechanical properties of steel X8CrNiS18-9, while the effect of the tellurium is considerably lower.
- Also, the addition of tellurium with zirconium and boron improves other properties of steel, especially machinability.

6. REFERENCES

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