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Professional paper

INFLUENCE OF BORON, ZIRCONIUM, AND TELLURIUM ON THE IMPACT TOUGHNESS OF X8CrNiS18-9 STEEL

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ABSTRACT

Steel X8CrNiS18-9 (standard EN 10088-3: 2005) is the most commonly used from the group of austenitic stainless steel in terms of machinability. The content of sulphur present in the steel from 0,15 to 0,35% has the exclusive task to improve the machinability. However, while sulphur improves machinability it simultaneously reduces the resistance of steel to corrosion but also affects the decrease in mechanical properties particularly steel toughness. Due to its harmful effect on the steel, as well as the fact that the non-metallic inclusions are insufficiently tested for this type of high-alloy steel the aim of this study is to determine the appropriate microalloying possibility to modify the non-metallic inclusions.

The aim of this work is that explore the influence of boron, zirconium, and tellurium on the impact toughness of the mentioned steel. Change of impact toughness, depending on the chemical composition of the steel is simulated with the Matlab program.

Keywords: impact toughness, boron, zirconium, tellurium, MATLAB

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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 the same kind. The high content of sulphur 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 the 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.

Of particular importance is to determine the behavior of nonmetallic inclusions in the process of manufacturing structural parts and in later exploitation. For this reason, it is planned to simulate the 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 on them.

Research on the influence of microalloying elements boron, zirconium, and tellurium on the modification of non-metallic inclusions in austenitic stainless steel X8CrNiS18-9 with the aim of reducing their negative impact on the properties of this stainless steel, included research on a number of properties starting from machinability, corrosion resistance, microstructure, and mechanical properties.

In this paper, we will consider exclusively the influence of the above-mentioned elements on impact toughness [1-3].

2. EXPERIMENTAL PRODUCTION AND PROCESSING OF STEEL X8CrNiS18-9

2.1. Melting and casting

In accordance with the program of testing eight melts with various contents of boron, zirconium and tellurium were produced. Melting and casting of austenitic stainless steel X8CrNiS18-9 were carried out in a vacuum induction furnace with a capacity of 20 kg, maximum power of 40 kW.

The first melt was austenitic stainless steel X8CrNiS18-9 without any modifiers. After that, in the following seven melts, the composition was modified with the appropriate content of boron, zirconium, and tellurium, so that each of the mentioned elements was added independently, then in combinations with two, and finally with all three alloying elements.

Preliminary research determined the content of each individual microalloying element and they were added to each melt in the same amount as follows: FeB (0.002 kg), FeZr (0.020 kg), and MnTe (0.015 kg). The chemical analysis of all melt variants is given in Table 1.

Table 1. Chemical analysis of all melt variants [4]

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 Te	0.05	0.40	0.80	0.010	0.16	18.9	9.3	–	–	0.033
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 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

2.2. Forging

After casting, all ingots are subjected to heat treatment: solution annealing – they are heated to a temperature of 1050 °C in a heating electric chamber furnace, and then quickly cooled in water.

After heat treatment, the samples were subjected to the forging on the press (Figure 1), and the final forging was done on an air hammer (Figure 2), approximately ∅ 50 mm. The set of samples after the forging process and the rough machining is shown in Figure 3.

2.3. Rolling

After forging and machining, the samples were subjected to a new degree of deformation by rolling. The first cross-section of the sample was reduced to □18 mm, and after the second passing through final sample dimensions were □14 x 50 mm. The rolling speed was 400 rpm. Figure 4 shows the all samples after the rolling process have been performed.

3. THE IMPACT TOUGHNESS

After completion of the forging and rolling process, the preparation for the impact toughness testing was started, and the geometry of the test sample is shown in Figure 5. The results of the test are given in Table 2.

Figure 1. Forging of ingots on a hydraulic press

Figure 2. Forging ingots on an air hammer

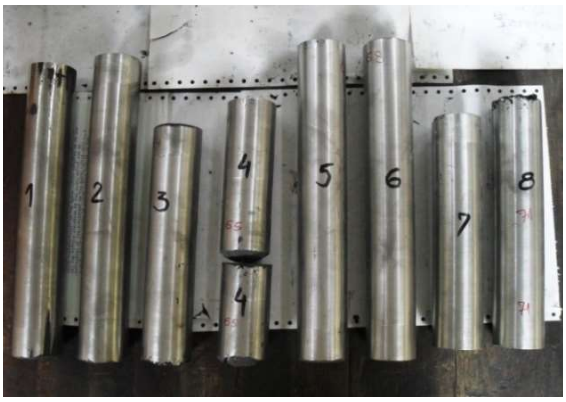


Figure 3. Samples after the forging process and rough machining

Figure 4. Samples after the rolling process

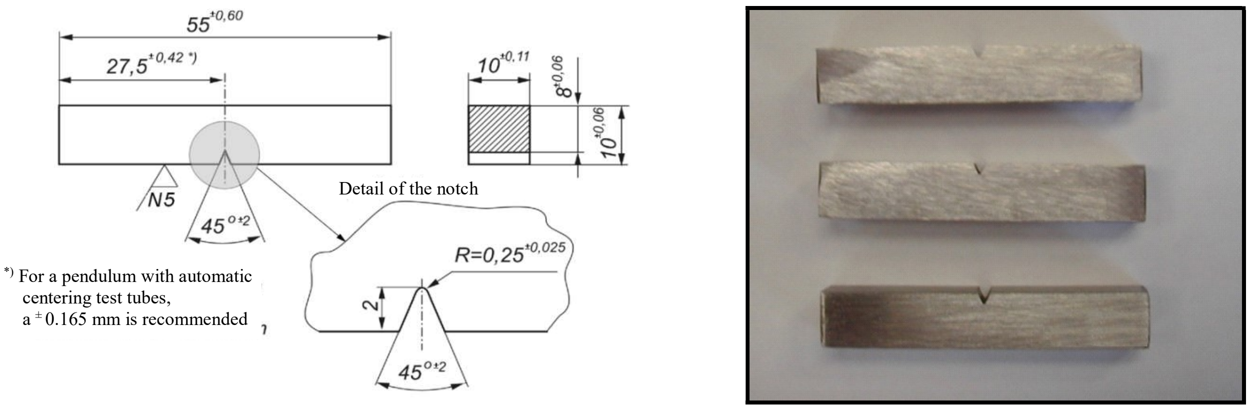


Figure 5. The shape and dimensions of the standard test samples for the impact toughness test

Table 2. Results of impact toughness test after the rolling process [4]

Melt variants	Impact toughness (J) KV 300 J	
	Individually (J)	Average (J)
Without alloying elements	60; 56; 56	57
Alloyed with B	48; 47; 59	51
Alloyed with Zr	55; 69; 55	60
Alloyed with Te	58; 69; 60	62
Alloyed with B and Zr	68; 69; 59	65
Alloyed with B and Te	75; 57; 71	68
Alloyed with Zr and Te	64; 69; 62	65
Alloyed with B, Zr and Te	57; 57; 63	59

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 impact toughness was performed using MATLAB 7.0 [5] software package. The analysis was conducted in the way that functional dependency results of impact toughness with the basic parameters of boron, zirconium, and tellurium content were requested.

4.1. Determination of the regression curve for the impact toughness (KV)

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 impact toughness is shown in Table 3.

Table 3. Impact toughness for different values of alloying elements [4]

Melt variants	B (%)	Zr (%)	Te (%)	KV_E (J)	KV_M (J)	Deviation (%)
Without alloying elements	0	0	0	57	54.651	-4.122
Alloyed with B	0.004	0	0	51	55.197	8.229
Alloyed with Zr	0	0.016	0	60	62.942	4.904
Alloyed with Te	0	0	0.033	62	64.549	4.110
Alloyed with B and Zr	0.004	0.009	0	65	59.861	-7.906
Alloyed with B and Te	0.004	0	0.039	68	66.894	-1.626
Alloyed with Zr and Te	0	0.007	0.04	65	62.542	-3.781
Alloyed with B, Zr, and Te	0.006	0.012	0.042	59	60.366	2.315

For the data from table 3, the regression coefficients, i.e. the regression equation (1), were calculated in the MATLAB software package:

$$KV_{M1} = 54,4716721 - 72,3501386 \cdot B + 454,8206726 \cdot Zr + 356,601515 \cdot Te + 103212,4804 \cdot B \cdot Zr - 16152,7494 \cdot B \cdot Te - 34383,21858 \cdot Zr \cdot Te \quad ....(1)$$

Adequacy of the model (1) was performed according to the Fisher criterion, where for the degrees of freedom $d_{freg} = 6$, $d_{frez.} = 1$ and the significance threshold $\alpha = 0.05$ tabular, or critical value $F_{(6,1,0.05)} = 233.97$ [6]. As the calculated value $F_{M1} = 0.378 < F_{Tab.} = 233.97$, the mathematical model for KV_{M1} is **not adequate**.

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 (2) was obtained. Table 4 gives the statistical characteristics of the given model (2).

$$KV_{M2} = 54.650654 + 136.564412 \cdot B + 518.223713 \cdot Zr + 299.934747 \cdot Te - 27619.486 \cdot Zr \cdot Te \qquad (2)$$

Table 4. Statistical characteristics of the impact toughness KVM [6]

KV_M	R^2	S_{ey}	$SS_{reg.}$	$SS_{rez.}$	F_{Mi}	F_{Tabi}	Significance
Condition after rolling	0.636	4.316	129.051	73.824	13.111	9.12	YES

The adequacy of the model (2) is checked by the Fisher criterion with degrees of freedom $df_{reg} = 4$, $df_{rez.} = 3$ and significance threshold $\alpha = 0.05$. Theoretically, the critical value from the corresponding Table is $F_{(4,3,0.05)} = 9.12$ [6]. Since the calculated value is $F_M = 13.111 > F_{Tab.} = 9.12$ the mathematical model for the impact toughness KV_{M2} is **adequate**.

Based on the obtained values of the correlation coefficients, conclusions were made about the nature and strength of the influence of individual independent variables, i.e. the most influential is the content of tellurium and zirconium, as well as the interaction of the influential factors of the first order zirconium-tellurium. Figure 6 shows a diagram illustrating the simultaneous influence of two factors on the objective function, for mathematical models of polynomial form (2). From the position of the lines on the impact toughness diagrams, it can be concluded that the interaction between the influencing factors of zirconium and tellurium exists (Figure 6a), while such interaction between boron and zirconium and boron and tellurium, does not exist (Figures 6b and 6c).

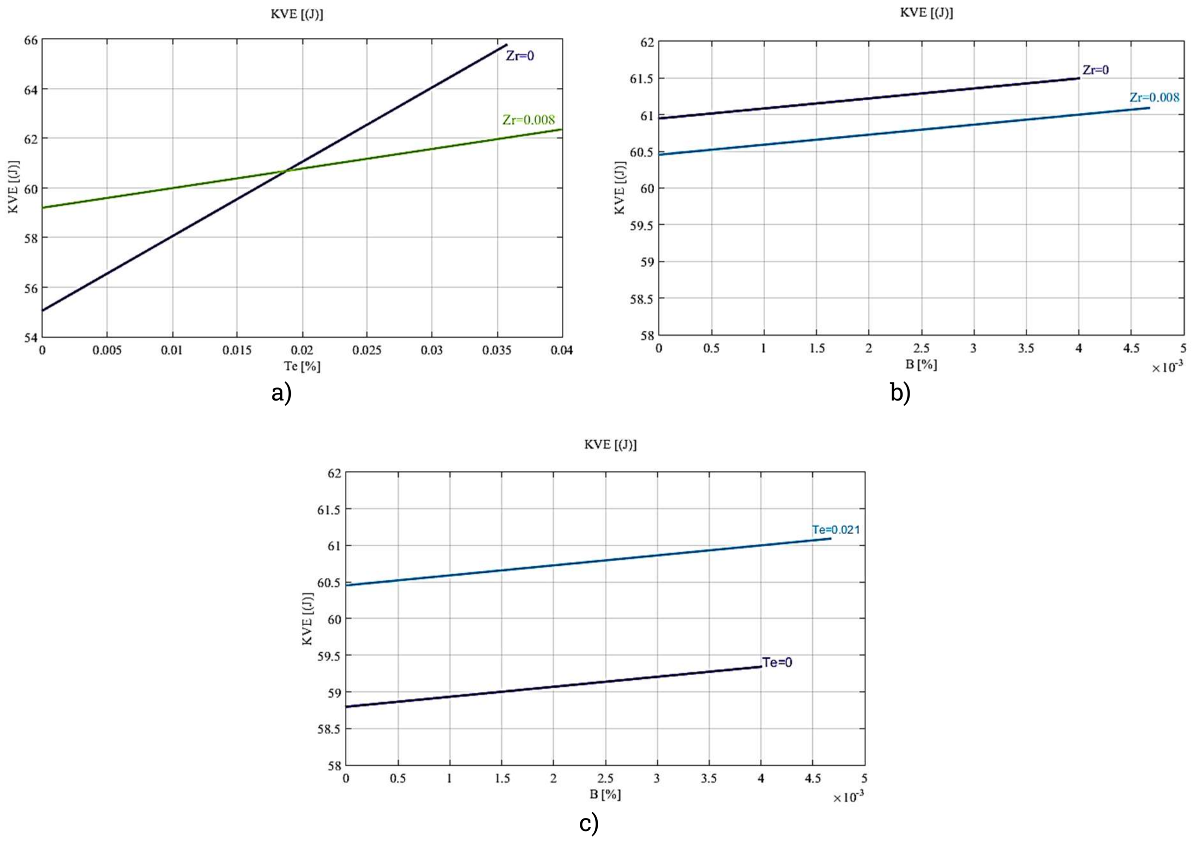
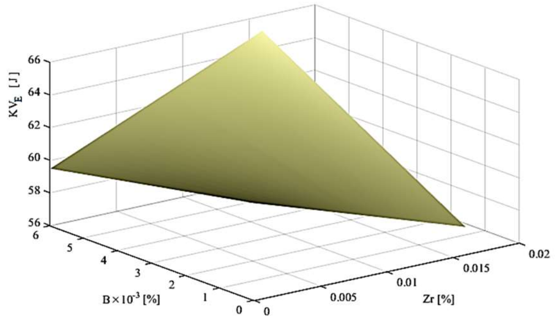
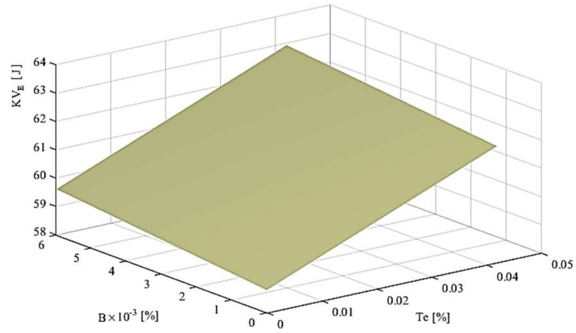


Figure 6. Effects of interactions of combined factors on impact toughness [4]

The subsequent analysis required the functional dependence of the results of the impact toughness and 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 7, for the mean values of the third component.





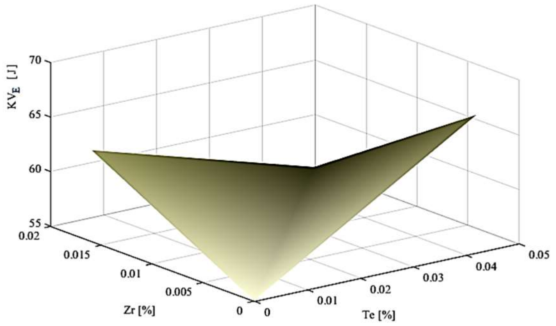


Figure 7. The functional dependence of the impact toughness on the content of B, Zr, and Te [4]

5. CONCLUSIONS

The objective was to determine the influence of boron, zirconium, and tellurium, on, the impact toughness of austenitic stainless steel X8CrNiS18-9 with the addition of sulphur.

Impact toughness tests were carried out in a rolled condition and the influence of chemical elements boron, zirconium, and tellurium on the impact toughness was monitored.

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

- An increase in the toughness value was observed in all variants of the melt, except for the melt alloyed only with boron, where a decrease in toughness was observed compared to the melt without alloying additions;
- The best combination of alloying elements in terms of increasing the toughness value is the combination of boron and tellurium.
- Based on the obtained results, it can be concluded that the addition of microalloying elements of boron (0.004 - 0.006%), zirconium (0.007 - 0.016%), and tellurium (0.033 – 0.042%) can improve the impact toughness of steel X8CrNiS18-9, especially in melt variants with combinations of the two said alloying elements.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] S. Kožuh, *Specijalni čelici* - skripta, Sveučilište u Zagrebu, Metalurški fakultet, Sisak, 2010.

[2] D. Mujagić, A. Mahmutović, M. Hadžalić, A. Karić, The influence of zirconium the machinability and impact energy of austenitic stainless steel, Proceedings of XI^th Scientific/Research Symposium with International Participation "Metallic and nonmetallic materials: production-properties-application", Zenica, BiH, April 21st-and 22nd 2016

[3] D. Mujagić, M. Hadžalić, A. Imamović, M. Oruč, S. Muhamedagić, Influence of boron, zirconium, and tellurium on the mechanical properties of austenitic stainless steel, Proceedings of XII^th Scientific/Research Symposium with International Participation "Metallic and Nonmetallic Materials: production-properties-application", Vlašić, B&H, April 19th and 20th 2018, p. 43-48

[4] D. Mujagić, *Doprinos istraživanju uticaja mikrolegiranja sa borom, cirkonijem i*

telurom na osobine austeninog nehrđajućeg čelika sa dodatkom sumpora X8CrNiS18-9 [doktorska disertacija], Univerzitet u Zenici, Metalurško – tehnološki fakultet, Zenica, 2017.

[5] D. V. Lazić, M. R. Ristanović, *Uvod u Matlab*, Univerzitet u Beogradu, Mašinski fakultet, Beograd, 2005.

[6] S. Ekinović, *Metode statističke analize u Microsoft Excel-u*, Univerzitet u Zenici, Mašinski fakultet, Zenica, 2008.