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THE INFLUENCE OF ZIRCONIUM ON THE MACHINABILITY AND IMPACT ENERGY OF AUSTENITIC STAINLESS STEEL

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ABSTRACT
Stainless steel plays an important role in all emerging technologies. Detrimental effects of inclusions in steel do not only depend on their sizes, shape, distribution, but also on their chemical composition and mechanical properties. For this reason, the control of formation of non metallic inclusions and the characterization present the basis of improvement of steel product properties and lead to sustainable development in design of new steel grades. In order to produce steels with better machinability, such as AISI 303 grades, a modification of inclusions with carefully designed chemical composition is presented. In this work detailed SEM/EDS analyses of inclusions – manganese sulphides modified by zirconium are presented. Also, the results of tests of machinability (cutting force and surface roughness) and impact energy for the melt without additions of alloying elements and with the addition of zirconium are presented.

1. INTRODUCTION
Stainless steel type 1.4305 or X8CrNiS18-9 (standard EN 10088-3:2005) is known as grade AISI 303 stainless steel. Grade AISI 303 is the most readily machinable of all the austenitic grades of stainless steel. The machinable nature of grade AISI 303 is due to the presence of sulphur in the steel composition [1-4].
The AISI 303 stainless steel referred to as "free-machining" stainless steel has the following nominal chemical composition, Table 1 [5].

Table 1: Nominal chemical composition of standard AISI 303 austenitic stainless steel (wt. %)

C	Mn	Si	Cr	Ni	P	S
0.15	2.00	1.00	17.0-19.0	8.0-10.0	0.2	0.15 min

The aim of the research was to examine the possibility of reducing the effect of sulphur on the mechanical properties of AISI 303 by microalloying with zirconium, which can modify the manganese sulfide and improve machinability.

2. INFLUENCE OF ZIRCONIUM ON STEELS

Zirconium is highly reactive and has a strong affinity, in decreasing order, for oxygen, nitrogen, sulphur, and carbon. Its affinity for oxigen, sulphur, and nitrogen is the primary reason for its use in steelmaking. Addition of zirconium prevents grain growth at typical reheating temperatures around 1200 ^oC. Also zirconium delays austenite crystallization, and prevents strain aging but its use for either of these reasons is limited.

When used as a micro alloying agent, zirconium recoveries are invariably quite low. However it is to be noted that the function of zirconium is not to remain in solution in steel but to scavenge oxigen, sulphur, and nitrogen impurities or modify inclusions through the formation of complex sulphides and oxy-sulphides.

Zirconium has strong ability to fix sulphur and hence can be used as a partial replacement for manganese to prevent hot shortness. Zirconium sulfide is significantly more stable than manganese sulfide in steel. Therefore, if enough free zirconium is available during the early stages of solidification of liquid steel, zirconium sulfide will form and prevent the formation of manganese sulfide. Zirconium sulfide is much more refractory than manganese sulfide and practically non deformable during hot rolling while, in aluminium killed steels, manganese sulfide produces long flat stringer inclusions in hot rolled steel.

Zirconium additions to low carbon and micro alloyed steels have been shown to be effective in improving toughness and ductility by forming (Mn, Zr)S inclusions, which are less plastic than manganese sulfide inclusions, and through grain refining of austenite, leading to a finer grain size [6].

Sulphides and silicates that exist in the zirconium free steel are modified into fine oxides in the zirconium bearing steel. When the zirconium contents range from 0,01 % to 0,03 %, the low temperature toughness of the steel can be substantially improved while its room temperature strength and ductility have no apparent change. The refinement of grain size by the addition of zirconium is one of the main reasons for this toughness improvement. Zirconium also raises the yield/tensile ratio and improves weldability through the reduction of under bead cracking and the elimination of porosity.

3. EXPERIMENTAL WORK

The aim of the research was to examine the possibility of improving machinability of AISI 303 stainless steel microalloying by zirconium. Zirconium seem to exert beneficial effects by promoting the retention of globular-shaped sulphide type inclusions [5].

The intention is to make better machinability of AISI 303 stainless steel but to keep good mechanical properties. Zirconium is considered to have a less harmful effect than sulphur on mechanical properties.

In the Department for melting and metal castings Metallurgical Institute "Kemal Kapetanovic", University of Zenica were made four melts based on austenitic stainless steel AISI 303; one of which was without alloying elements and the other alloyed with zirconium.

Melting and casting of austenitic stainless steel AISI 303 was carried out in a vacuum induction furnace with a capacity of 20 kg, the maximum power of 40 kW. This furnace is intended for the production of liquid metal of high purity.

After casting the ingots were all subjected to heat treatment: solution annealing – in the first heated to a temperature of 1050 °C, then rapidly cooled in water.

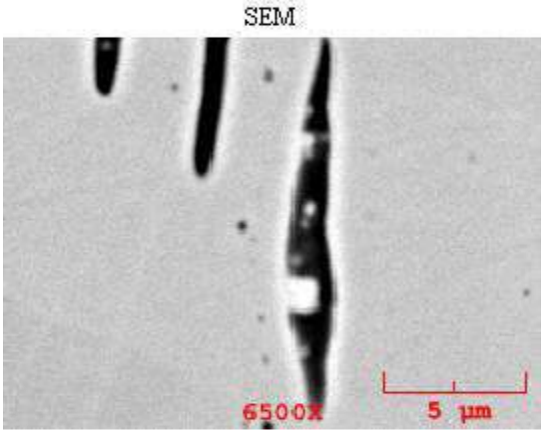
The chemical composition of the produced melt austenitic stainless steel AISI 303 is given in Table 2.

Table 2: Chemical composition of modified AISI 303 austenitic stainless steels, (wt. %)

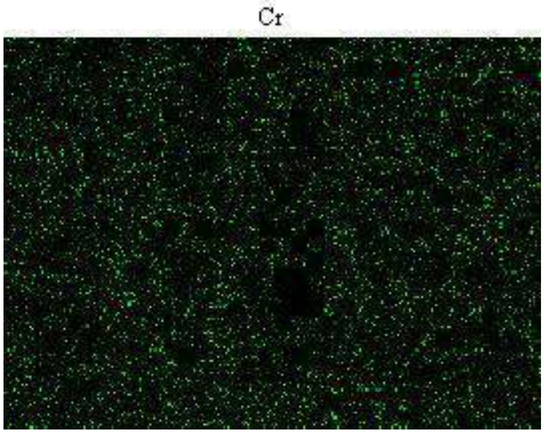
Designation of melt	*Chemical composition (%)*								
	C	*Si*	*Mn*	*P*	*S*	*Cr*	*Ni*	*B*	*Zr*
AISI 303	0.03	0.42	0.61	0.021	0.18	18.3	9.4	–	–
AISI 303+Zr	0.04	0.35	0.75	0.021	0.17	18.8	9.4	–	0.016

3.1. SEM results of non-metallic inclusions of steel modified by zirconium

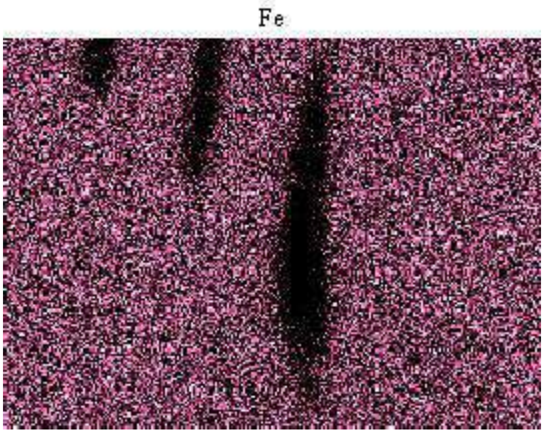
Figure 1 presents elemental distribution of typical non-metallic inclusions for the stainless steel AISI 303 modified by zirconium performed by scanning electron microscope (SEM) Jeol JSM 5610 with attached energy-dispersive x-ray spectroscopy (EDS) system Gresham Scientific Instruments Ltd., Model No.: Sirius 10/SUTW at accelerating voltage of 15 kV. EDS maps show an increase of concentration of manganese, sulphur and zirconium which means that these are complex manganese sulphides connected on zirconium-oxyde-sulphide.



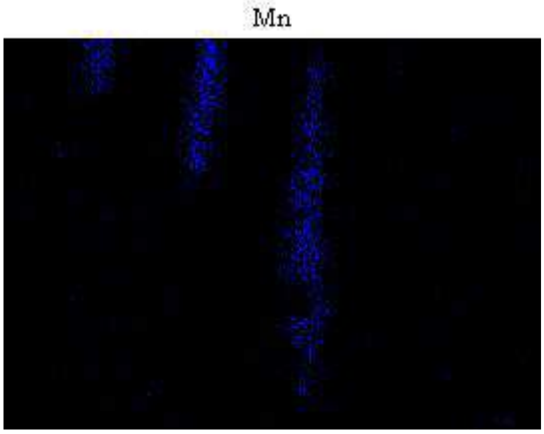
a)



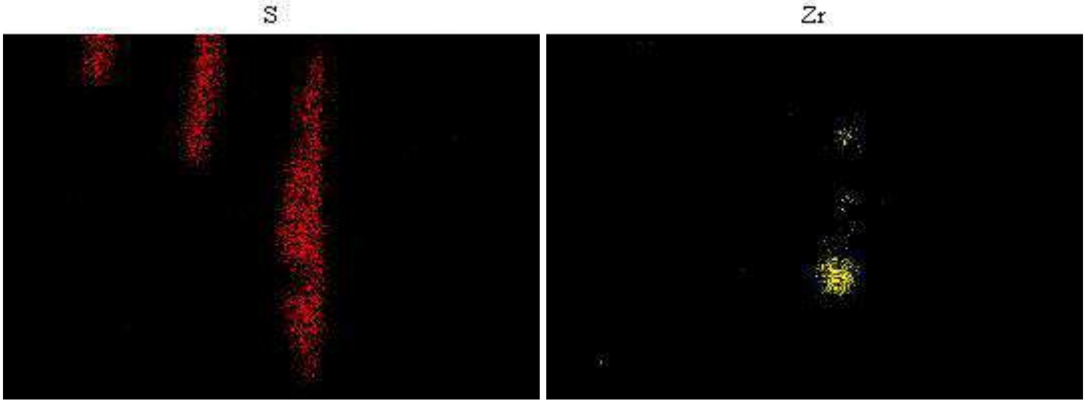
b)



c)



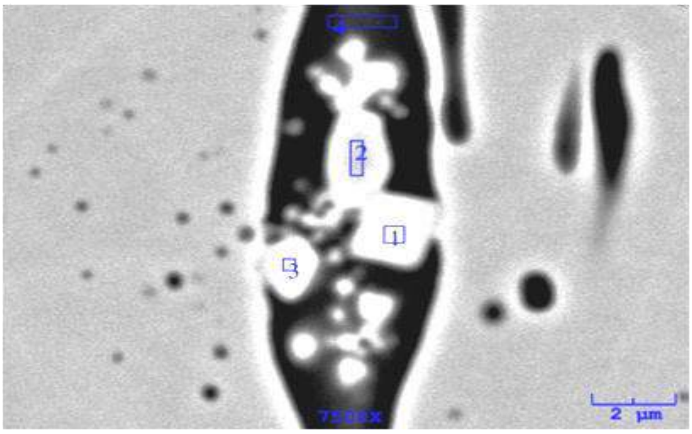
d)

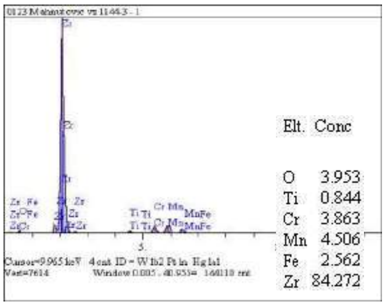


e) *f)*

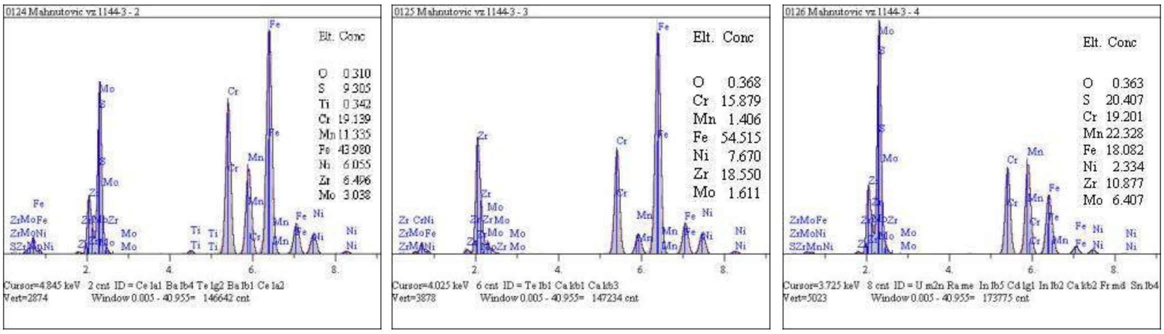
Figure 1: SEM and EDS maps of chromium, iron, manganese, sulphur and zirconium of non-metallic inclusion in AISI 303 stainless steel modified by zirconium.

In high chromium steel like AISI 303, zirconium can form complex precipitates which can occur in micro-segregation bands. Zirconium can affect the shape of manganese sulfide inclusions.
Figure 2 shows the analysis of the points of one of the inclusions featured SEM image.





a) *b)*



c) *d)* *e)*

Figure 2: Analysis of the points of one of the inclusions featured SEM image: a) SEM image; b) – e) diagrams of detected elements with chemical analysis in weight percents

For each of these points, numbered 1-4 on the SEM image (Figure 2a), are presented diagrams of the content of the detected elements in the weight percents (Figure 2b-2e). Based on the analysis in these diagrams, it can be concluded that the presented inclusion are complex inclusion, which in addition to manganese sulphide, also contains other elements, in this case zirconium and oxygen (point 1 and diagram 2b), which probably formed zirconium oxides, and molybdenum and nickel (points 2, 3 and 4 on the SEM image, or diagrams 2c, 2d and 2e).

3.2. The test results of cutting forces and the impact energy

Tests of cutting forces and the impact energy are conducted on four samples of the materials of different chemical composition and mechanical characteristics (AISI 303) [7].
The experiments, which results are presented in this paper were conducted at the Laboratory for metal cutting and machine tools (LORAM) at Faculty of Mechanical Engineering. The machine PA 501 M manufactured by Potisje was used for the cutting test. Testing, for all the samples, performed in the same treatment regimen with the following parameters:

$$n = 600 \text{ r / min}, s = 0{,}1 \text{ m}, d = 1{,}0 \text{ mm}$$

where: n - number of rotations; s - feed rate and d - depth of tools penetration.
The surface roughness values of finish-cutting workpieces were measured by Perthometer M1 instrument.
For examination impact energy the standard Charpy specimens 10 x 10 x55 mm are used.
Results of cutting forces, surface roughness and the impact energy are provided in Table 3.

Table 3: Results of cutting forces, surface roughness and the impact energy [7]

Designation of melt	*Cutting forces F_R (N)*	*Surface roughness R_a (µm)*	*Impact energy (J) KV 300 J (Average value)*
AISI 303	458.52	1.287	57
AISI 303+Zr	445.21	1.080	60

As we can see from these results, the parameters of machine processing (both the cutting force and surface roughness) decrease, while impact energy increases with the addition of zirconium in the melt.

4. CONCLUSION

In order to produce steels with better machinability, such as AISI 303 grade, the effects of zirconium on modification of inclusions with carefully designed composition are presented. By chemical effects on the formation of non-metallic inclusion the nature of inclusions can be changed. In AISI 303 steel alloyed with zirconium the inclusions consist of complex particles. Those complex inclusions – manganese sulphide connected on zirconium-oxyde-sulphide effectively acting as saving breakers. With inreasing of zirconium content cutting force decreases and impact energy increases. The AISI 303 modified grades have better machinability compared to standard AISI 303 grade and with the mechanical properties in the limits prescribed for AISI 303 standard grade.

5. REFERENCES

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