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Original scientific paper

TELLURIUM MICROALLOYING OF AUSTENITE STAINLESS STEEL X8CrNiS18-9

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ABSTRACT

More recently 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) is the most commonly used from the group of austenitic stainless steel in terms of machinability. This steel has high mechanical and working properties thanks to a complex alloying, primarily with elements such as chromium and nickel. The content of sulphur present in the steel from 0.15 to 0.35% improves machinability. However, sulphur at the same time decreases the mechanical properties, particularly toughness. In steel, tellurium stabilizes carbides and reduces the microporosity of the structure. Also, tellurium is now recognized as a powerful sulphur modifier as well as a machinability additive when used in combination with lead and sulphur.

This work aims to determine the influence of tellurium on the machinability, corrosion resistance and mechanical properties of the mentioned steel.

Keywords: nonmetallic inclusions, tellurium, machinability, corrosion resistance, mechanical properties

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1. INTRODUCTION

Tellurium in the periodic table of the elements belongs to the group consisting of oxygen and sulphur [1]. It appears in the form of telluride in steel. Due to the extremely low melting point of iron telluride, Figure 1, (1187 K – 914 °C), which is precipitated in the form of a film at the boundaries of the primary grains, tellurium must be bound to manganese [2,3].

The presence of tellurium in steel leads to the formation of globular sulphide inclusions, which at the same time favorably affect the machinability of steel, since its presence in steel reduces the energy required to separate the material in the shear zone during cutting. This is due to the low melting point of manganese telluride (1428 K – 1155 °C) [3], which is lower than the melting point of manganese sulphide in Figure 2 [2], and the very high chemical surface activity of tellurium.

The addition of tellurium to improve the cut surface is due to the lubrication ability of manganese telluride. In sulphur alloy steels, tellurium always occurs as telluride because it is minimally soluble in manganese sulphide (0.01%). Tellurium occurs in steels in inclusions in the form of manganese (sulpho) telluride ($MnTe_xS_{(1-x)}$), as a white envelope of manganese sulphide, or in the form of globular inclusions, which are at the base of manganese sulphide or manganese silicate. The formation pattern depends on the tellurium content of the steel. It is necessary to consider the ratio Mn : S = 4 and Mn : Te = 20.

Otherwise, during hot processing, characteristic cracks occur along the edges of the intermediate products [1].
Tellurium is added to copper and low-carbon steels as it improves their mechanical processing capability. In steel, it stabilizes carbides and reduces the microporosity of the structure [4]. Modification of sulphide inclusions in steel on globular morphology makes progress in product quality. Tellurium is now recognized as a powerful sulphur modifier as well as a machinability additive when used in combination with lead and sulphur [5].

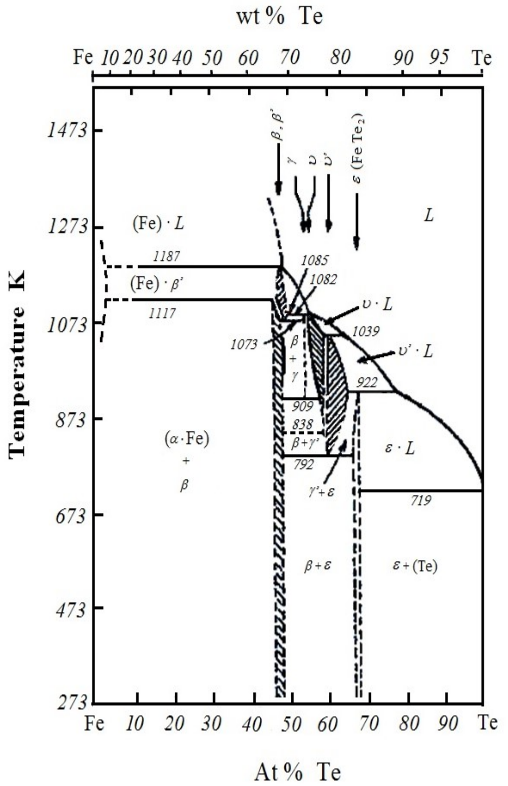

Figure 1. Fe – Te binary phase diagram [2,3]

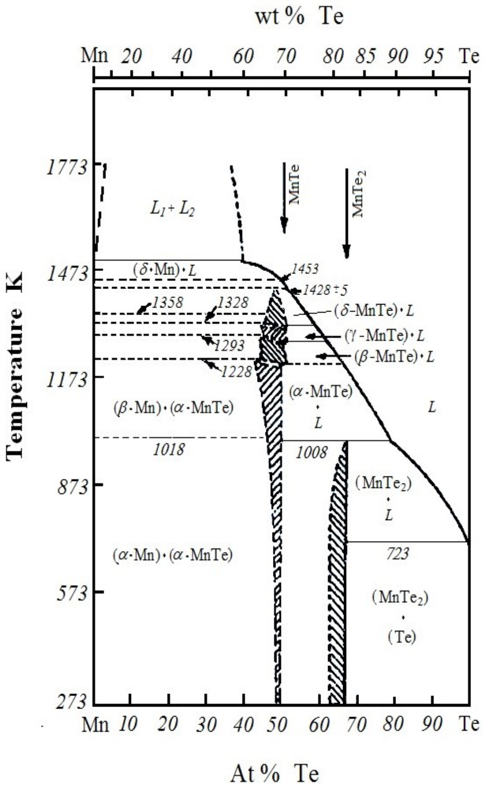

Figure 2. Mn – Te binary phase diagram [2,3]

Tellurium forms manganese telluride (MnTe) inclusions and is more effective than sulphur for the machinability of austenitic stainless steels. As well as selenium, it also promotes globularization and expansion of sulphide inclusions. However, tellurium causes problems with the hot processing of austenitic stainless steels and has not been used for commercial purposes [6].

2. EXPERIMENTAL RESEARCH AND TEST RESULTS

The aim of the research was to examine the influence of the tellurium on machinability, corrosion resistance and mechanical properties of austenitic stainless steel X8CrNiS18-9. Production of austenitic stainless steel X8CrNiS18-9 was performed in a vacuum induction furnace at the Institute "Kemal Kapetanović" in Zenica. The ingots (Figure 3), were processed by forging and hot rolling. After casting, all ingots are subjected to heat treatment: solution annealing - they are heated to a temperature of 1050 °C in an electric box furnace, and then quickly cooled in water. The chemical analysis of the two melt variants is given in Table 1.

Figure 3. Ingot after the solidification process [7]

Table 1. Chemical analysis of melt variants [7]

Melt variants	Chemical composition (wt %)							
	C	Si	Mn	P	S	Cr	Ni	Te
Without Te	0.03	0.42	0.61	0.021	0.18	18.3	9.4	–
With Te	0.05	0.40	0.80	0.010	0.16	18.9	9.3	0.033

In preliminary research, it was planned that after primary processing of the ingot (approx. to diameter 50 mm) samples are tested by cutting forces, 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 manufacturing structural parts and in later exploitation. For this reason, it is planned to simulate processing of austenitic stainless steel by plastic processing (forging and rolling) with two different degrees of processing. After that, the samples will be taken for laboratory testing of mechanical properties.

Using electron probe microanalyzer type of inclusions were confirmed, whereas chemical composition and formed non-metallic inclusions were determined. SEM Elemental Mapping and EDS scan methods were used to examine the exact chemical composition of sulphides in masse percents.

2.1. 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 the 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.

Table 2. The results of the cutting force tests [7]

Melt variants	Cutting force (N)			The resultant force F_R (N)
	Component F_x	Component F_y	Component F_z	
Without Te	180	218	361	458,52
With Te	154	200	317	405,22

The melt with tellurium has significantly lower the resultant cutting force and accordingly significantly better machinability compared to melt without alloying elements.

2.2. 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 [7]

Melt variants	Corrosion current, I_{Corr} (μA)	Corrosion rate, v_{Corr} (mm/year)	Open Circuit Potential, $E_{(I=0)}$ (mV)
Without Te	4.266	4.955	-475.320
With Te	8.949	10.390	-504.517

The melt with tellurium has a significantly worse corrosion rate compared to melt without tellurium.

2.3. 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.

Table 4. Test results of tensile properties and impact toughness in rolled condition [7]

Melt variants	0,2%-proof 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 (J)	Average (J)
Without Te	349	670	50,0	70	60 56 56	57
With Te	314	635	46,5	59	58 69 60	62

The melt with tellurium has slightly worse tensile strength, but also slightly better impact toughness value compared to melt without tellurium.

2.4. Testing of samples at SEM in the rolled condition

The final tests were performed at the Scanning Electron Microscope (SEM) type JEOL JSM 5610 of Japanese production at the Faculty of Natural Sciences and Engineering, University of Ljubljana. Tests were carried out on samples in a rolled condition as the final stage of processing. Point analysis and mapping were done for each of these samples.

Figure 4 shows the point analysis of individual inclusions presented by the SEM image. For each of the mentioned points in the SEM picture (Figure 4a), diagrams of the contents of individual elements are given, on which chemical analysis of the detected elements in mass per cent is also given. Based on the analysis of diagram 4b, it can be concluded that the inclusions formed in the sample are mainly the inclusion of manganese sulphides (point 1 in SEM)

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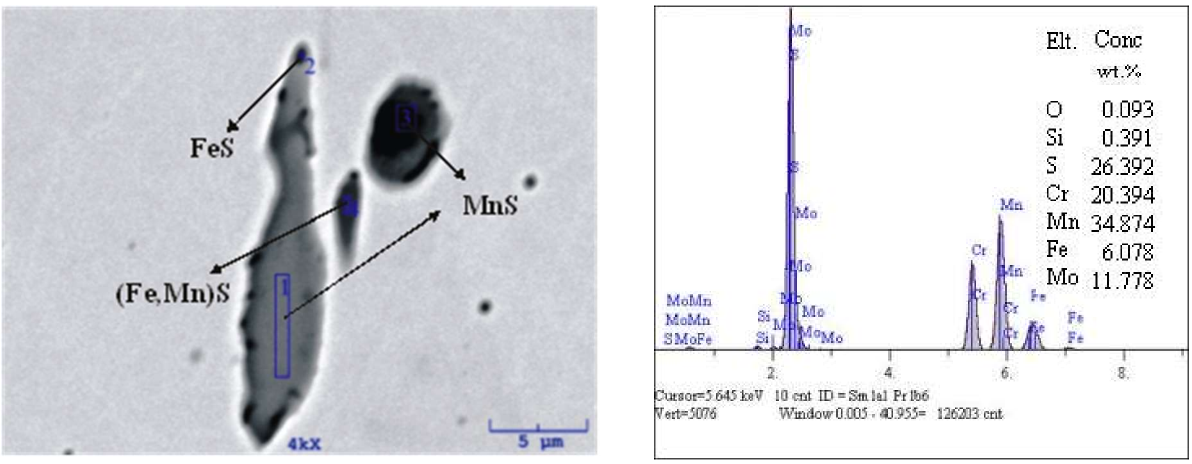
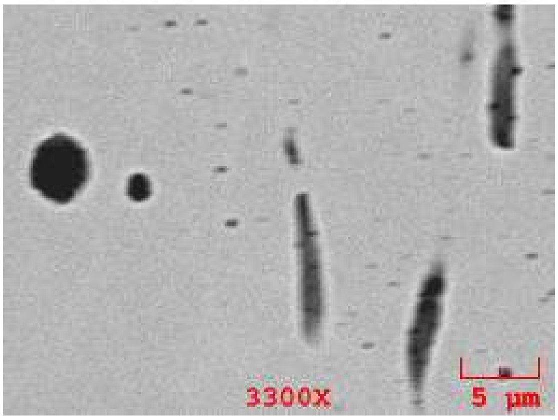


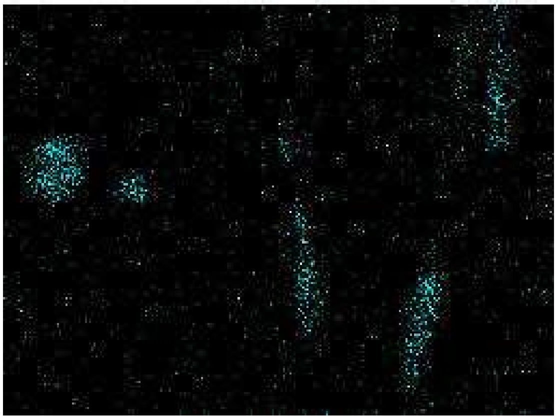
a) b)

Figure 4. Point analysis of sample inclusions without Te: a) SEM image; b) diagram of detected elements with chemical analysis in mass percentages [7]

Figure 5 shows the mapping where each of the elements represented by the mapping is about the SEM image, showing the inclusions of the sample without tellurium. It is clear from the picture that the inclusions from the SEM image (Figure 5a) are almost identical to those in the images showing the position of manganese and sulphur (Figures 5b and 5c). Figure 6 shows a point analysis of the inclusions presented by the SEM image.



a)



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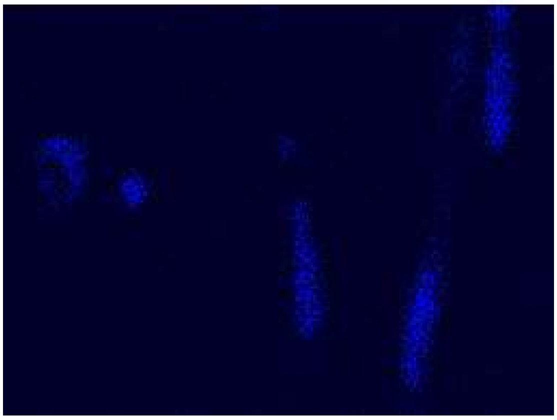
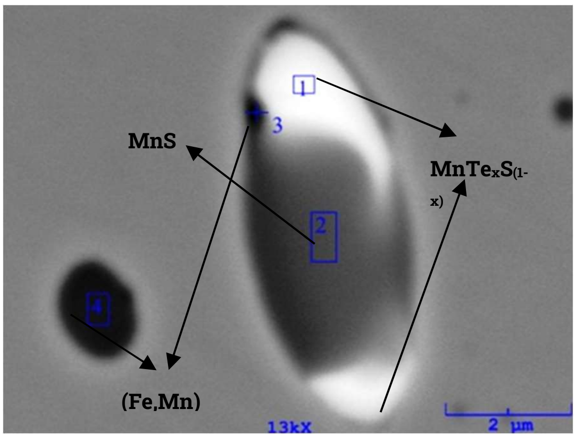
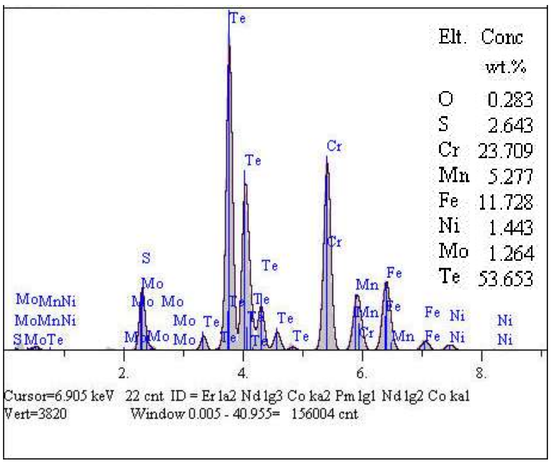


c)

Figure 5. Mapping of the sample without Te: a) SEM image; b) and c) Mn and S elements [7]



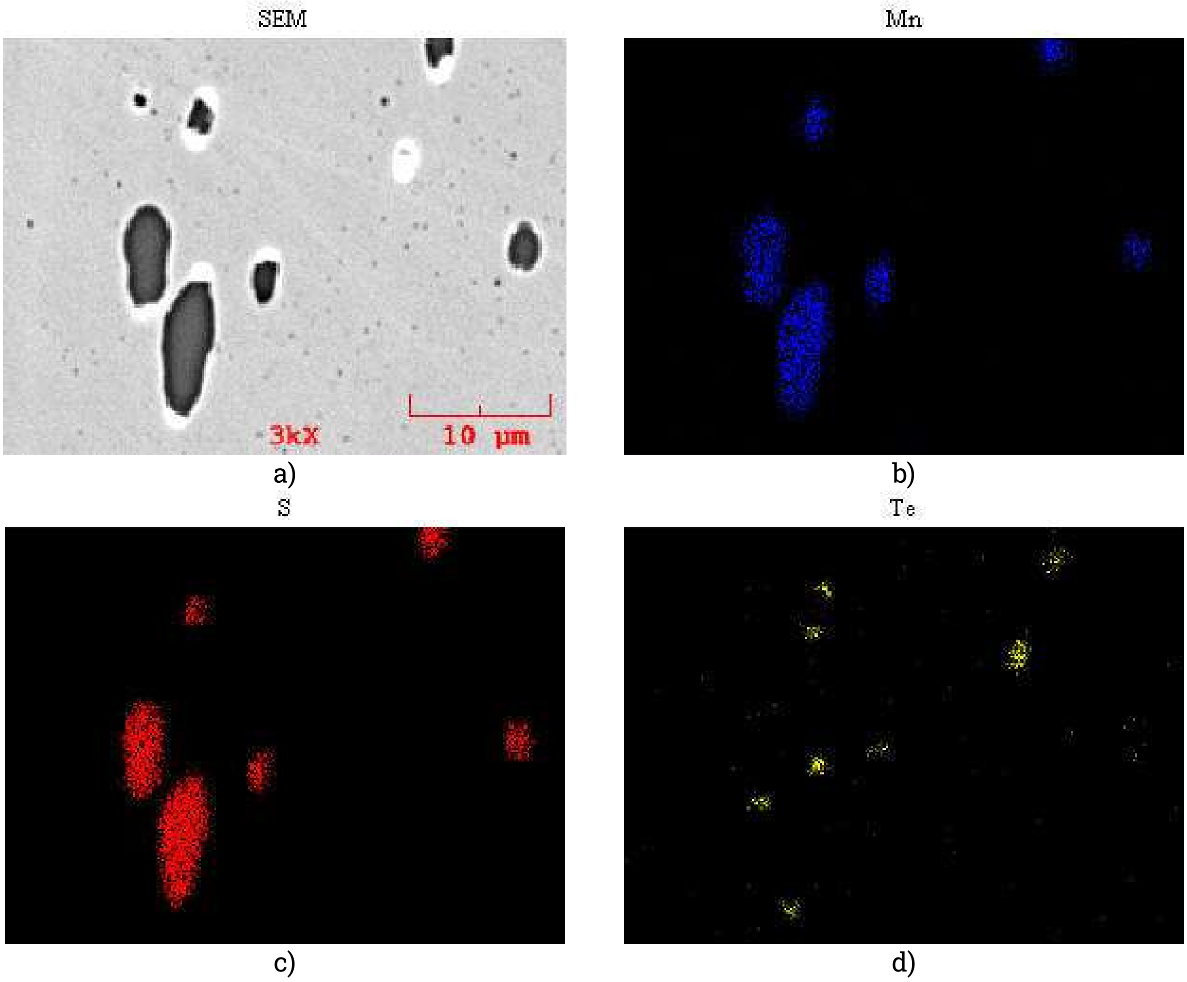
a)



b)

Figure 6. Point analysis of inclusion of the sample with tellurium: a) SEM image; b) diagram of detected elements with chemical analysis in mass percentages [7]

For each of the points, marked with numbers 1 to 4 in the SEM picture (Figure 6a), diagrams of the contents of individual elements are given, which also contain chemical analysis of the detected elements in mass percentages. Based on the content of individual elements in diagram 6b, it can be concluded that the displayed larger inclusion is complex inclusion, which, in addition to manganese sulphide, contains other elements, in this case, tellurium (point 1, diagram 6b, as well as edge sections of the inclusions), in the form of manganese (sulpho) telluride ($MnTe_xS_{(1-x)}$), or as a white envelope of manganese sulphide.



a) b) c) d)

Figure 7. Mapping a sample with tellurium: a) SEM image; b) - d) Mn, S and Te elements [7]

Figure 7 shows the mapping where each of the elements represented by the mapping is about the SEM image, which shows the inclusions of the sample with the addition of tellurium. It is clear from the picture that the inclusions from the SEM image (Figure 7a) are almost identical to those in the images showing the position of manganese and sulphur (Figures 7b and 7c). Also, based on the comparison of the SEM image with the image indicating the tellurium distribution, it can be concluded that the tellurium is practically in all the inclusions shown in the SEM picture, mainly at their ends (Figure 7d).

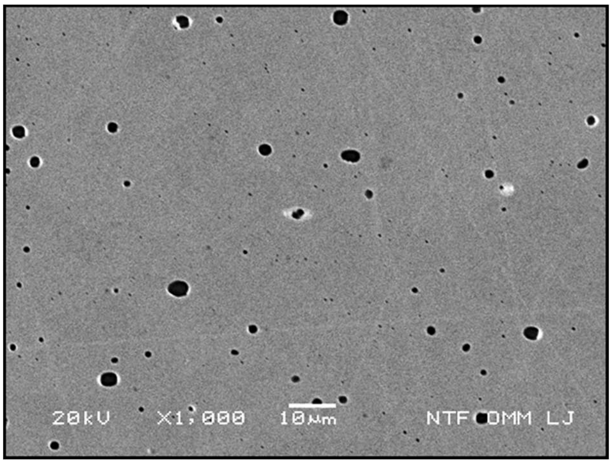


Figure 8. Tellurium, as a white envelope around manganese sulphide inclusions [7]

The steel with the addition of tellurium has characteristically manganese sulphides combined with a tellurium which are a typical globular shape and specifically improve the machinability of this steel, in the form of white envelopes, which is also consistent with the literary citations, Figure 8.

3. CONCLUSIONS

The research aimed to determine the effects of tellurium in austenitic stainless steel with the addition of sulphur X8CrNiS18-9 on the machinability, corrosion resistance and mechanical properties of the mentioned steel.

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

Nonmetallic inclusions of manganese sulphide types, in combination with a tellurium, can be translated into a suitable form, whose shape is more spherical. These inclusions are more effective than pure sulphide in free-machining austenitic stainless steels, while effectively acting as shaving breakers and thus they improve machinability.

About the effect of tellurium on the corrosion rate of austenitic stainless steel X8CrNiS18-9, it can be concluded that melt with tellurium shows a marked increase in corrosion rate compared to melt without tellurium.

But, on the other hand, all values of tensile properties (tensile strength, proof strength, elongation and reduction) as well as impact toughness are within the limits prescribed by the relevant standard for the steel X8CrNiS18-9.

It has been found that the basic types of inclusions in this steel are manganese sulphides and that the nonmetallic inclusions in austenitic stainless steel X8CrNiS18-9 can be modified by the addition of tellurium.

Conflicts of Interest:

The authors declare no conflict of interest.

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