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EFFECT OF TEMPERATURE ON THE MECHANICAL PROPERTIES OF X5CrNi18-9 STEEL

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Preliminary Note – Prethodno priopćenje

The results of static tensile tests conducted on a selected steel grade with austenitic matrix are discussed in this paper. The tensile tests were carried out at the following temperatures: 200°, 400° and 700 °C. Under the conditions of the static tensile test, all the samples failed with a characteristic "necking" forming a cup-conical shape. It has been found that with increasing temperature the strength properties decrease and the elongation increases. The microscopic examinations of the fractures showed that they were mostly plastic, and numerous "dimples" were filled with non-metallic inclusions characterized by a globular shape and a size of up to 8 μm.

Keywords: austenitic steel, mechanical properties, tensile test, fracture, scanning electron microscopy (SEM)

INTRODUCTION

Steels containing 18 % of Cr and 9 % of Ni belong to the most widely utilised group of steels, characterised by a stable austenitic structure in a wide temperature range from negative (they are not entering a brittle state) up to high (good resistance to oxidation) [1,2]. Basic, stabilising austenite elements are Ni and Mn. However for steels, which are applied at high temperatures the content of C is increased or Cu is introduced to improve their creep resistance [3]. Austenitic steels have very good plastic properties. At a room temperature: tensile strength (R_m) min. 500 MPa, yield strength (R_V) 185 - 230 MPa, impact energy 55 - 86 J, elongation (A) up to 45 % [4,5]. A ferrite content of approximately 3 % is allowable in commercial steels. A ferrite presence is disadvantageous, since these precipitates constitute preferential places for precipitating of carbides or intermetallic phases rich in Cr [5,6]. In addition, holding these steels at increased temperatures leads to precipitation of complex carbides containing - in dependence of steel chemical compositions - Cr, Mo, Nb, Ti (precipitating at a temperature range: 700 - 900 °C) [2,6]. In a similar way the presence of intermetallic phases of σ phase, significally decreases cast steels properties. The results of investigations obtained from the static tensile tests performed at three temperatures, are presented in the here by paper.

TEST MATERIAL

Tests were performed on samples made of Cr - Ni steel of the chemical composition shown in Table 1. The chemical composition obtained from the performed spectrometric analysis and taken from standard ISO/TS 15510: 2003, are listed in Table 1.

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Table 1 **Chemical composition of the investigated austenitic steel / wt. %**

Grade / Designation	Components contents / wt %							
	C	Si	Mn	P	S	Cr	Ni	other
X5CrNi18 - 9	max 0,07	max 1,0	max 2,0	0,045	0,03	17,5 19,5	8,0 10,5	max 0,11 N
A	0,03	0,3	1,2	0,015	0,007	18,1	8,3	-

Samples of a diameter 3 mm and length 45 mm were rolled from the supplied materials in the direction perpendicular/parallel to the rolling direction. Samples were used for performing static tensile tests at temperatures: 200°, 400° and 700 °C. The static tensile tests were performed by means of Instron 5566 device equipped with a special heating furnace, in which fluctuations of temperature were not exceeding ± 2 °C. Before each test samples were held in the furnace for 15 minutes at the temperature at which the test was planned. Samples were pulled with a deformation rate $\varepsilon = 10^{-3}$

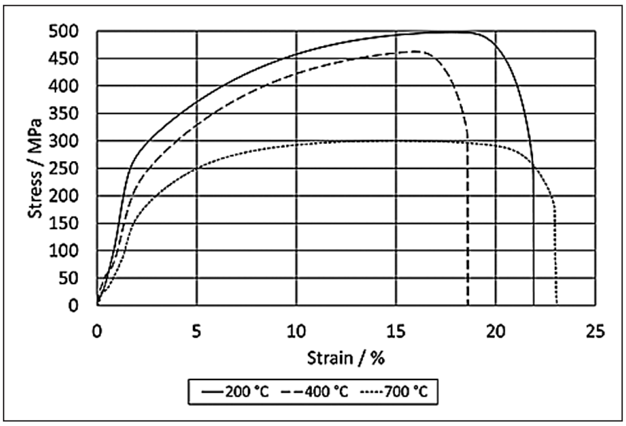


Figure 1 Examples of tensile curves obtained for the tested material at various temperatures

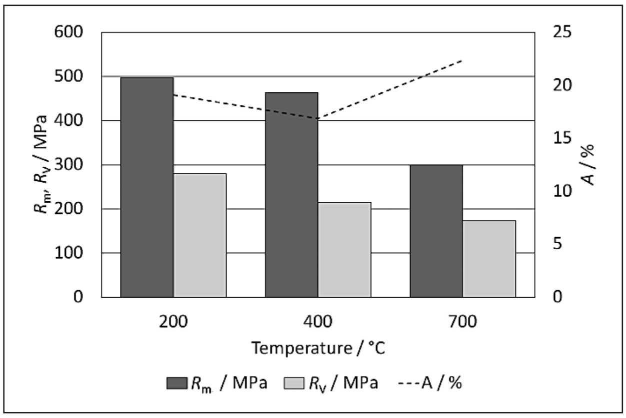


Figure 2 Changes of properties of the tested steel when the temperature of investigations was changed

1/s. After breaking, all samples were water cooled to the ambient temperature. Three samples were ruptured at each temperature. Next, the average tensile strength (R_m), yield strength (R_V) and elongation (A), were calculated from the obtained results.

Table 2 **Dependence of R_m, R_V and A on test temperatures (average of three measurements)**

Temperature / °C	Average strength properties		
	R_m / MPa	R_V / MPa	A / %
200	496	279	19
400	463	215	17
700	299	173	22

In addition, fractographic investigations of the obtained ruptures were carried out by means of the scanning microscope HITACHI 3200N. After breaking the selected samples were cut lengthwise and laterally and their microstructure was observed in the direction parallel to the applied tensile force.

EXPERIMENTAL RESULTS

Examples of tensile diagrams obtained for the tested cast steel are shown in Figure 1. In accordance with ex-

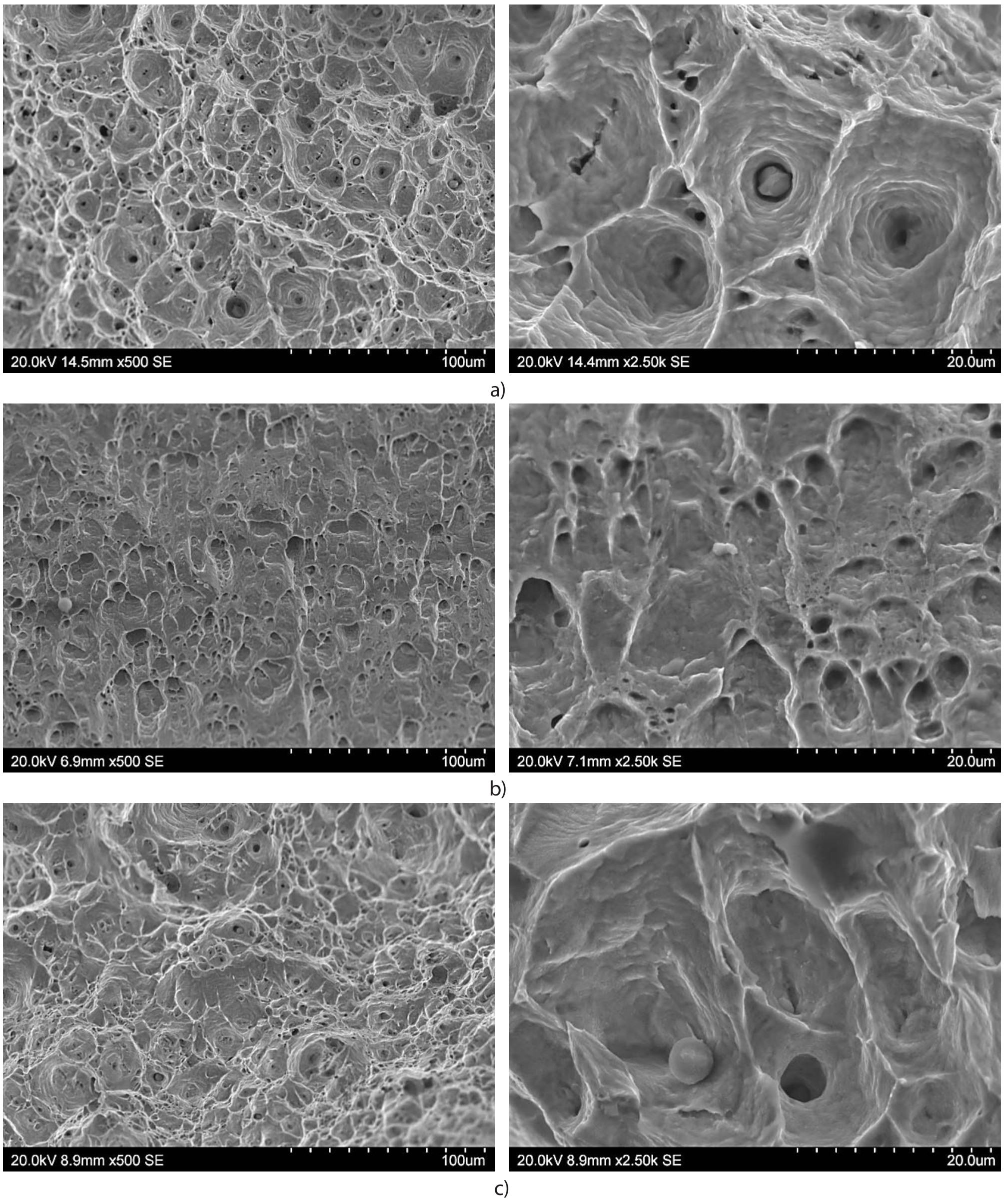
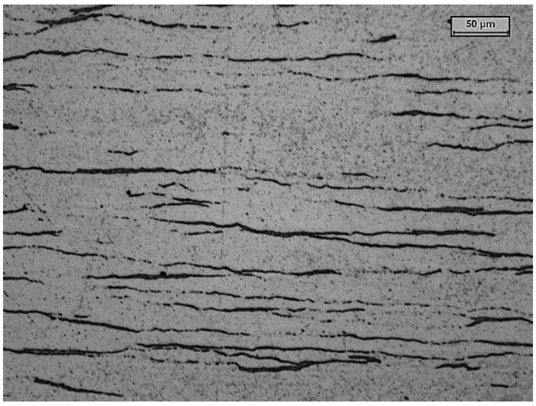
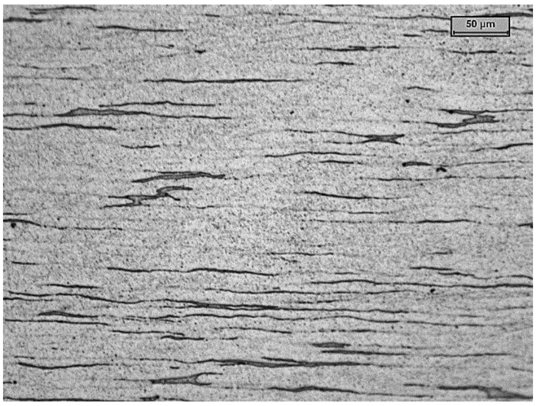


Figure 3 SEM image of samples after the static tensile tests performed at temperatures: a) 200°, b) 400° and c) 700 °C



a)



b)

Figure 4 Microstructure of the cross-section parallel to the tensile force operation: a) 200 ° and b) 400 °C

pectations the tested material does not have a distinct yield strength.

Results of strength tests of Cr - Ni steels are presented in Table 2 and in Figure 2. In accordance with expectations strength properties of the tested material are decreasing when the temperature of the test is increasing. At a temperature of 700 °C the tensile strength decreases by 197 MPa (i.e., approximately by 60 %), and yield strength by 106 MPa (i.e. approximately by 38 %) as compared with the results obtained at a temperature of 200 °C. A different situation is in case of elongation. It is lower at a test temperature of 200 °C than at a test temperature of 700 °C. However, it is worth to notice that at a temperature of 400 °C the elongation value is lower than at a temperature of 200 °C. Low measured values can be caused by small diameters of the samples applied in investigations as well as by the non-metallic inclusions amount and/or other brittle phases precipitating in the microstructure of tested steels at increased and high temperatures [2,6].

Visual assessments of samples after the static tensile test indicated that all samples were ruptured with characteristic narrowing in the breaking place. In addition, on each rupture a deposited layer was seen (more distinct the higher the temperature) formed due to the influence of the temperature, at which the given test was performed.

Views of ruptures obtained during observation in the scanning microscope are shown in Figure 3. On the bases of the performed investigations it was found, that ruptures of samples indicated elastic character. Their topography is characterised by a developed surface of cracking and consists of many craters, which have various sizes and shapes. SEM fractographs indicated that, as a result of single axis tensile, craters were mainly forming spherical dimples. Only in case of the rupture pulled at a temperature of 400 °C it is possible to notice on its surface, that discontinuities have slightly different shape, corresponding to parabola. Such shape of craters is related to their joining along plates of the tangent stresses maximum. Performed observations revealed that at the bottoms of craters occurred phases of shapes similar to spherical ones and of sizes reaching approximately 6 µm. (e.g., non-metallic inclusions or carbide precipitates) [7,8].

Examples of microstructures of cross-sections parallel to operations of the tensile force, are presented in Figure 4. The tested cast steel was characterised by the austenitic structure with ferrite precipitates appearing in bands. The ferrite banding probably corresponds to the direction of the metal forming process of the tested steel.

CONCLUSION

1 The tested steel cross-section parallel to the breaking direction was characterised by the austenitic matrix with ferrite precipitates in a bands form.

2 It was found, that R_m and R_v values of the tested cast steels were decreasing when the temperature of the performed tests was increasing. In case of elongation such correlation was not found.

3 The obtained fractures are of a ductile character, however they differ in morphology of the formed craters. Fractographic investigations revealed also the presence of spherical dimples in the bottom of craters.

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Note: The responsible translator for the English language: ANGOS Translation Office Krakow, Poland