Effect of heat treatment and test temperature on fracture type of steel Nitronic 60

Vpliv toplotne obdelave in temperature preizkušanja na vrsto preloma jekla Nitronic 60

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Abstract: Nitronic 60 is a commercial name for austenitic stainless steel. Requirements in terms of chemical composition and mechanical properties of steel Nitronic 60 meet the requirements for steel UNS S21800. This steel has an increased content of manganese and silicon, which contributes to its excellent resistance to abrasion and adhesive wear. In this paper the fracture surface of the specimen after tensile test were examined in order to detect changes in ductile properties and the type of fracture depending on the condition of material and test temperature. Analysis of the fracture surface was performed on the stereo, optical and scanning electron microscope.

Izvleček: Nitronic 60 je komercialno ime za avstenitno nerjavno jeklo. Glede na kemijsko sestavo in mehanske lastnosti jeklo Nitronic 60 izpolnjuje zahteve za jeklo UNS S21800. To jeklo ima povečano vsebnost mangana in silicija, ki prispevata k odlični odpornosti proti abraziji in adheziji. V tem delu smo preiskali prelomne površine vzorcev po nateznem preizkusu in spremljali spremembe duktilnih lastnosti ter ugotavljali vrsto preloma v odvisnosti od stanja materiala in temperature preizkušanja. Za analizo prelomnih površin smo uporabili stereo-, optični in elektronski mikroskop.

Original scientific paper

Key words: Nitronic 60, brittle fracture, ductile fracture, fracture surface
Ključne besede: Nitronic 60, krhek prelom, duktilni prelom, prelomna površina

Introduction

Because of the unstable and high nickel price on the world market there is a need for replacing expensive nickel with some other cheaper austenite stabilizing elements.[1, 2] The solution of this problem is substitution a portion of nickel with manganese and nitrogen. In this way a new steel group was created, which according to the UNS (Unified Numbering System) system, referred to as the series 200. In this group of steel nitrogen content ranges from 0.08–0.6 %, manganese 4–19 % and nickel 0.5–18 %.[3, 4] Nitronic 60 is a commercial name for austenitic stainless steel, which according to their chemical composition belonging to series 200. Steel Nitronic 60 has excellent resistance to abrasion and adhesive wear due to an increased content of manganese and silicon. Compared to steel alloyed with nickel and cobalt, Nitronic 60 has the same or better properties and lower price. Also, it has good impact resistance at low temperatures. Steel Nitronic 60 is applied to work at elevated temperatures because of good creep resistance and high temperature corrosion resistance.[5] The ASTM standard for this group of steels prescribes mechanical properties in the annealed condition, hot or cold deformed. This paper presents and discuss the results of the analysis of fracture surface of the specimens after tensile test at room and elevated temperature for three corresponding chemical composition of test material in a rolled and annealed condition.

Materials and methods

Tests were conducted using three melts produced in a vacuum induction furnace (type- Heraeus) at the Metallurgy Institute „Kemal Kapetanović“ in Zenica. The results of chemical analysis of the experimental melts and comparative values prescribed by ASTM standards are given in Table 1.

As seen from the Table 1 the chemical composition of test melts is in good agreement with chemical composition as prescribed in ASTM A276. This standard applies to steel S21800, which is taken as a reference for Nitronic 60.

Mechanical and metallographic examinations were conducted on samples in a rolled and solution annealed state. To obtain the austenitic microstructures free of precipitates extracted samples were

Table 1. The chemical composition of melts –Nitronic 60[5] in mass fractions, *w*/%

Melt	Chemical composition, *w*/%							
	C	Si	Mn	Cr	Ni	P	S	N
ASTM A276	≤0.10	3.5–4.5	7–9	16–18	8–9	≤0.006	≤0.03	0.08–0.18
V1694	0.04	3.74	8.6	18.0	8.0	0.007	0.005	0.160
V1696	0.05	3.5	7.9	16.9	8.6	0.005	0.005	0.120
V1697	0.05	3.5	7.2	16.9	8.6	0.005	0.010	0.168

Table 2. Test results of mechanical properties of steel Nitronic 60[5]

Melt	Test condition	Test temperature	Mechanical properties			
			$R_{p0.2}$/(N/mm^2)	R_m/(N/mm^2)	Z/%	A/%
V1694	rolled	Room temperature	860	1026	50	18.1
V1696			681	874	68	35.6
V1697			779	937	61	27.9
V1694	annealed	Rom temperature	400	750	75	51.8
V1696			331	681	76	57.2
V1697			366	716	68	55.7
V1694	annealed	750 ^{0}C	211	292	49	38.7
V1696			158	245	48	45.5
V1697			182	299	42	29.9

Figure 1. Microstructure of austenitic stainless steel Nitronic 60. (aqua regia, × 100)[5]

annealed at a temperature of 1020 °C for 1 h and quenched in water. Microstructure of austenitic stainless steel Nitronic 60 is shown in Figure 1 with polygonal austenite grains with the characteristic twins. The basic parameters of the mechanical properties of tested samples are presented in table 2. Mechanical tests were conducted on a universal hydraulic machine for static testing (200 kN) at the Metallurgical Institute »Kemal Kapetanović« in Zenica. The process of testing and preparing of test specimens for testing performed in accordance with the standards BAS EN 10002-1/02 and BAS EN 10002-5/01. Tensile testing of mechanical properties at room and elevated temperature (750 °C) was carried out on specimens obtained from the Ø 15 mm rod.

Test results from Table 2 for annealed samples tested at room temperature are in agreement with the standard ASTM A276. while the test results for annealed samples tested at elevated temperature are in accordance with the manufacturer demand.

Examination of the fracture surface appearance was performed in three steps.

- Analysis of fracture surfaces on specimens at the stereo microscope Leica with a maximum magnification of 60-times
- 3D simulation of the fracture surface of specimen using Olympus optical microscope with appropriate software. Development of the simulation was based on a series of photographs taken on the optical microscope with magnification of 50-times
- Analysis of the fracture surface using SEM Jeol JSM 5610 at different magnifications.

Results and discussion

Analysis of the tensile test results

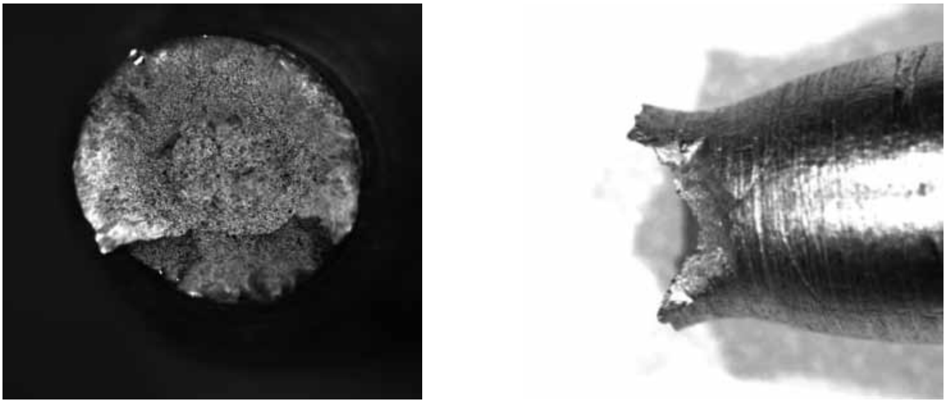
Analysis of the results of mechanical tests showed that the material in the rolled condition has the maximum value of tensile properties, while the increase in temperature leads to decreasing of the strength. Specimens tested in annealed condition at room temperature have the best ductile properties. These results are a consequence of the microstructure obtained for different tasted states.

Annealing at temperatures above 1000 °C leads to dissolution of precipitates, mainly $M_{23}C_6$ type of carbides, which have a negative effect on the ductility properties.[6] However, heating austenite steel in the temperature range from 400–900 °C leads to their re-precipitation. Otherwise, the final rolling temperature was an average of 850 °C, which affected the amount of extracted precipitates, and thus the ductility and tensile properties of tested material.

Fracture surfaces analysis

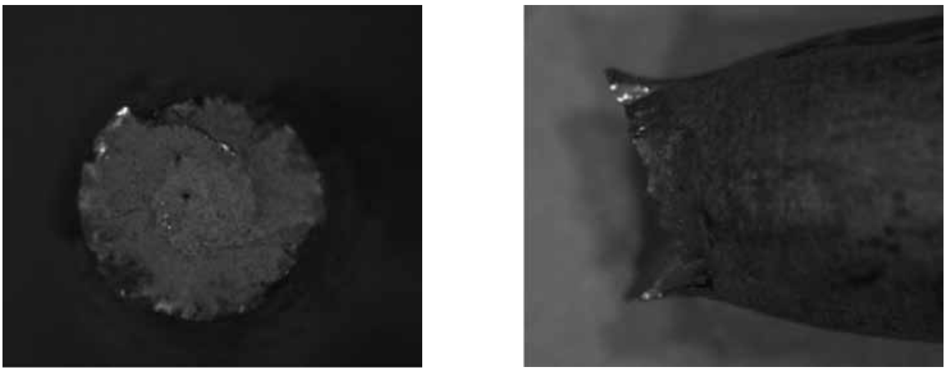
Stereo microscope analysis

Figures 2, 3 and 4 give the appearance of the fracture surfaces of tested specimens made from melts V1696, V1694 and V1697. From Figure 2 and 3 can be seen that the fracture surface of specimens tested at room temperature made of melts V1696 and V1694 have typical Cup-Cone ductile fracture with pronounced plastic deformation while this type of fracture is not present at the specimen made from melt V1697 tested at of 750 ° C



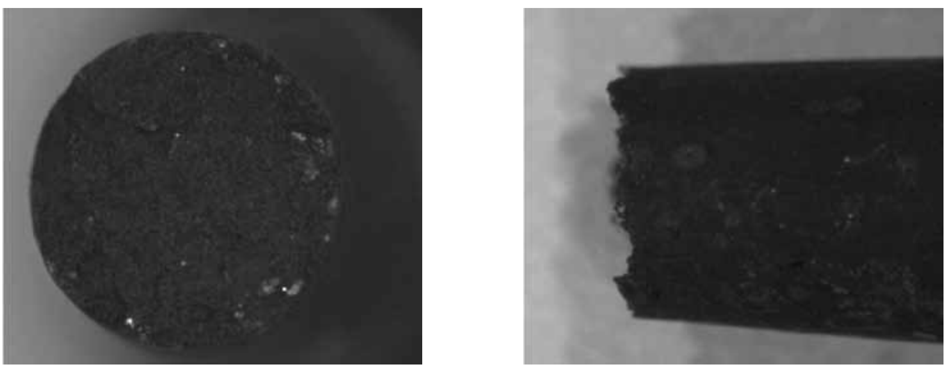
a) magnification 20-times b) magnification 12.5-times

Figure 2. Fracture surface (melt V1696, rolled condition, room temperature)



a) magnification 16-times b) magnification 16-times

Figure 3. Fracture surface (melt V1694, annealed condition, room temperature)



a) magnification 16-times b) magnification 12-times

Figure 4. Fracture surface (melt V1697, annealed condition, tested at 750 °C)

Optical microscope analysis

Samples presented in the previous chapter were used for 3D analysis of fracture surface. The appearance of the obtained fracture surface is shown in Figures 5, 6 and 7. Analysis of 3D images of the fracture surface confirmed the assumption after observing the samples at a stereo microscope. At the figures 5 and 6 can be observed ductile type of fracture, while in Figure 7 the brittle fracture characteristics can be seen.

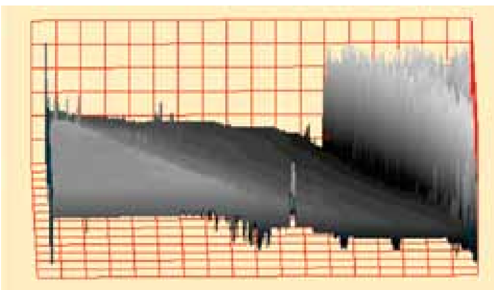


Figure 5. 3D view of fractured surface (melt V1696, rolled condition, room temperature)

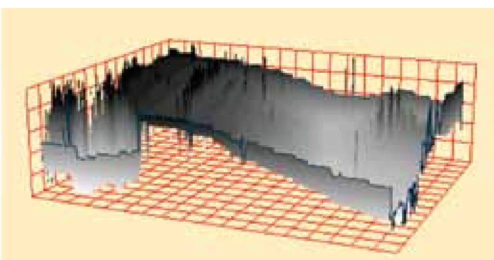


Figure 6. 3D view of fractured surface (melt V1694. annealed condition, room temperature)

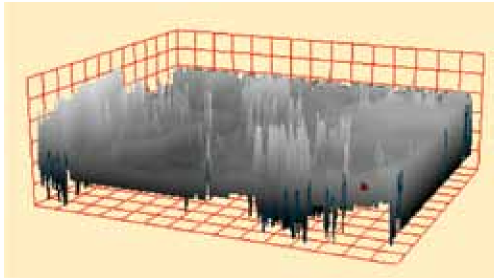


Figure 7. 3D view of fractured surface (melt V1697, annealed condition, test temperature 750 °C)

SEM analysis of the fracture surfaces

SEM (scanning electron microscope) analysis was carried out for a detailed analysis of the type of fracture. SEM micrographs were used for confirmation the assumptions made after stereo and optical microscope analysis. The analysis was performed at the University of Ljubljana (Faculty of Natural Sciences and Engineering) at the scanning electron microscope JEOL at different magnifications. Analysis of fracture surfaces showed that the ductile fracture occurs during testing at room temperature in both cases, i.e. in rolled and annealed conditions of samples. Fracture surfaces of samples tested at 750 °C showed the presence of intergranular brittle fracture with small portion of ductile fracture. Appearance of fracture surfaces of specimens is shown in Figures 8, 9,10 and 11 which is consistent with the 3D fracture analysis.

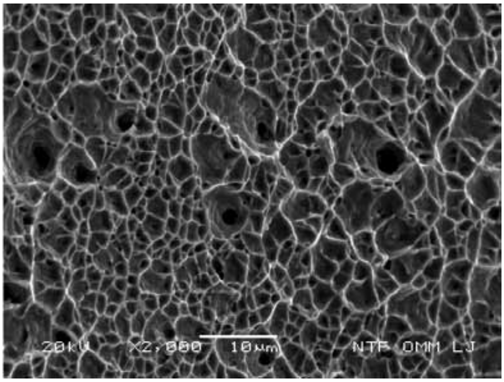


Figure 8. Fracture surface – SEM (melt V1696, rolled condition, room temperature)

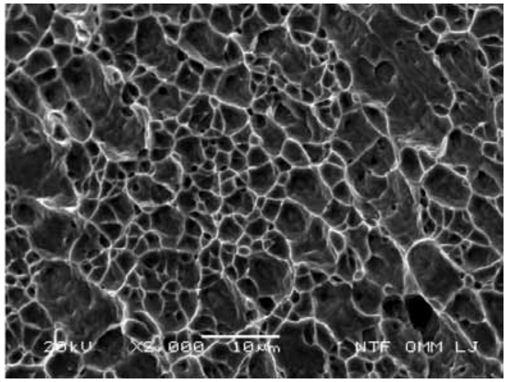


Figure 9. Fracture surface – SEM (melt V1694, annealed condition, room temperature)

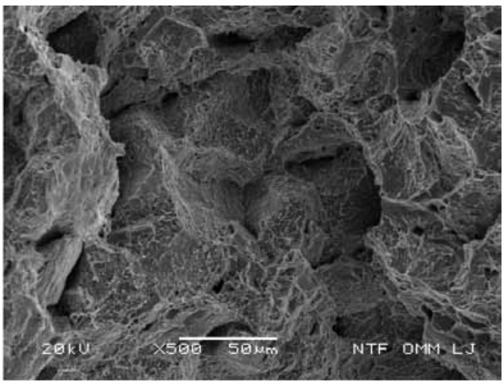


Figure 10. Fracture surface – SEM (melt V1697, annealed condition, tested at 750 °C)

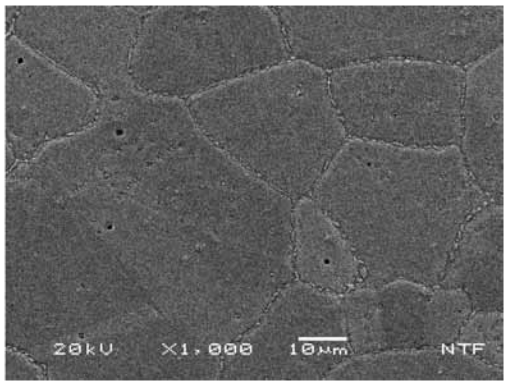


Figure 11. Microstructure of the sample – SEM (melt V1697, annealed condition, tested at 750 °C)

Conclusions

On the basis of the research and analysis of the results it can be concluded that the tensile test specimens tested at room temperature in a rolled and annealed condition have ductile fracture, while during testing at 750 °C appears brittle intergranular fracture.

Samples that were solution annealed have austenitic microstructure without extracted precipitates inside the grains and at grain boundaries what has a significant influence on the ductile properties and the type of fracture.

Temperature rising during testing at 750 °C leads to excretion of the first precipitates at grain boundaries and then inside the grains, which leads to a decrease in ductile properties and the occurrence of brittle fracture, Figures 10 and 11.[5]

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