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Effect of Heat Treatment on the Microstructures 20%Cr-21%Ni-5%Si Cast Steel

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Abstract

The study describes the effect of heat treatment on the microstructure of cast high-alloyed 20%Cr-21%Ni-5%Si steel. It has been found that the microstructure of the tested material in the initial state consists of an austenitic matrix and precipitates rich in Si, Cr, Ni and Mn, characterized by different morphology and distributed mainly along the grain boundaries. The conducted heat treatment (after solutioning at: 1060, 1100 and 1200ºC) has changed both morphology and chemical composition of the precipitates. Significant reduction in the Si and Ni content and slight increase in the Cr content, especially after solutioning at 1200°C, combined with a simultaneous decrease in the hardness of the precipitates was evidenced.

Keywords: Austenitic cast stainless steels, Microstructures, Heat treatment

1. Introduction

Cast high-alloyed 20%Cr-21%Ni-5%Si steel belongs to the group of materials resistant to the effect of both heat and corrosion. The high content of silicon (3.5÷5.5%) in corrosion-resistant Cr-Ni steels improves their resistance to corrosion and stress corrosion cracking in an oxidizing atmosphere of concentrated nitric or sulphuric acid [1÷5]. This effect is mainly due to the change and stabilization of the chemical composition of an oxide layer formed on the steel surface. In the austenitic 18%Cr-8%Ni type steels, silicon (1÷5%) addition increases the corrosion resistance in the environments of concentrated nitric and sulphuric acid and in the oxidizing environments [3÷5]. Additionally, as proved in study [6], in aqueous solutions of chlorides, a small amount of silicon added to ferritic-austenitic steels changes the structure of a passive layer and passivation mechanism.

At the same time, the microstructure of the stainless Cr-Ni steel with an increased silicon content has been observed to promote the formation of δ ferrite [7]. In these steels, the presence of silicon may also lead to the extended occurrence of brittle phases, mainly σ phase, in the temperature range of 600÷1000°C. Therefore, in duplex steels, the content of this element is reduced to 1% [8].

The article describes studies that were conducted to characterize the microstructure of cast 20%Cr-21%Ni-5%Si steel in the initial state and after heat treatment.

2. Methods of investigation

For tests the cast steel was melted in an induction vacuum furnace. The weight of the charge was 1kg. The charge was composed of alloy scrap, armco iron, metallic Cr, Ni and FeSi, FeMn. The chemical composition of the tested material is shown in Table 1.

Microstructure in the initial state and after solutioning from the temperature of 1060, 1100 and 1200°C was examined by light microscopy and scanning electron microscopy using a JSM-7100 JEOL microscope with EDX detector. The volume fraction of the precipitates was calculated by the grid method [9]. Microhardness of structural components was determined using a Hanemann attachment to Neophot 32 microscope. The structure of the matrix obtained in castings and of the base Allom was examined using a Kristalloflex 4HX-ray diffractometer (Siemens, Germany) with Cu Karadiation ($\lambda = 0.1548$ nm).

Table 1.
Chemical composition of the examined 20%Cr-21%Ni-5%Si cast steel, wt. %

Materials	C	Mn	Si	Cr	Ni	Mo	P	S	Al	Ti	V
Cr-Ni-Si	0.14	17.9	8.53	20.04	21.5	0.24	0.025	0.014	0.05	0.01	0.06

3. Results and discussion

The conducted X-ray diffraction analysis of the tested cast steel has showed that its matrix was composed of austenite (Fig. 1). In addition to the austenitic matrix, the as-cast steel microstructure also contained the precipitates of different morphology distributed mainly along the grain boundaries (Fig. 2).

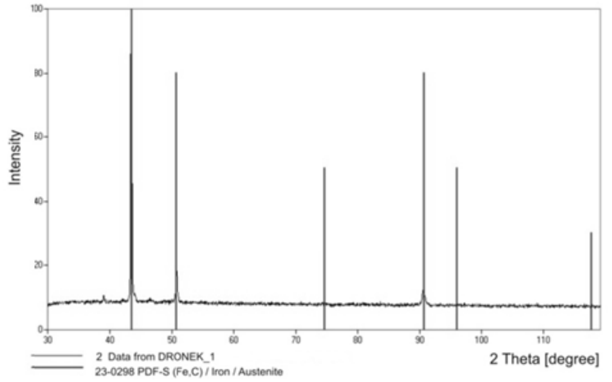
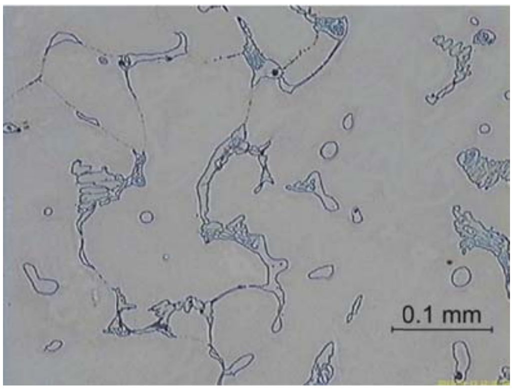


Fig. 1. X-ray diffraction patterns of the investigated cast steel

a)



b)

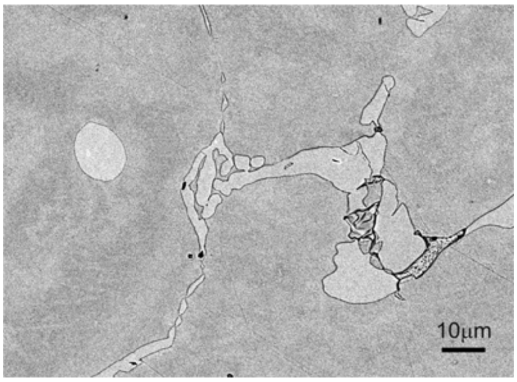


Fig. 2. Microstructure of the investigated cast steel in as-cast, a) light microscope, b) SEM

Chemical analysis of the precipitates has indicated that, compared with the alloy matrix, they were rich in Si, Cr, Ni and Mn (Fig.3, 4). The average content of Si was 9.7%, and of Cr, Ni and Mn - 24.7, 24.2, 1.9%, respectively (Fig.4). The precipitates additionally showed the presence of a peak originating from Mo. The content of molybdenum in the examined areas did not exceed 0.6%.

In the initial state, the precipitates were characterized by a microhardness of 710÷830 μHV_{20}, with the matrix microhardness approaching 210÷230 μHV_{20}.

In the steel microstructure, the presence of scarce precipitates of complex nitrides containing Ti (50.5%), Cr (15.7%), V (3.6%), N (22.6%) was also detected - areas 3, Fig.3,

On the other hand, in an austenitic matrix, the average content of silicon was 6.1%. The content of Cr, Ni and Mn was also lower and amounted to 20.8, 22.1 and 1.1, respectively. Figure 5 shows an example of the X-ray spectrum of the matrix and its chemical composition.

Compared with austenitic matrix, the matrix located between the Si-rich precipitates (Fig.3, p.1) was impoverished in Si and Cr - areas 4 and 5 in Figure 3.

The conducted cast steel heat treatment has mainly changed the morphology and distribution of the precipitates (Fig.6, 7).

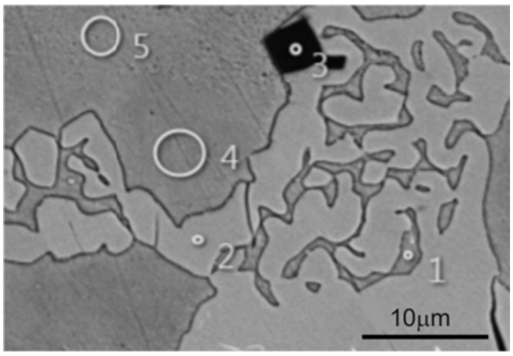
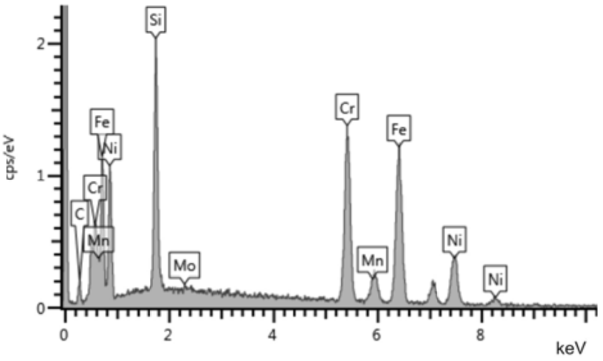
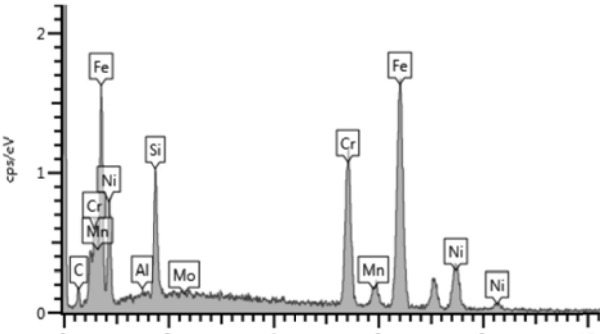


Fig. 3. SEM image of cast 20%Cr-21%Ni-5%Si steel in as-cast with marked areas of the EDX microanalysis



Results of the EDX microanalysis of precipitate –p.2, wt.%					
Si	Cr	Ni	Mn	Mo	Fe
9.9	21.9	26.4	2.1	0.6	39.1

Fig. 4. X-ray spectrum with energy dispersion (EDX) from the precipitate Fig. 3, and its average chemical composition



Results of the EDX microanalysis of matrix, wt.%					
Si	Cr	Ni	Mn	Mo	Fe
5.8	21.2	21.3	1.1	-	56.4

Fig. 5. X-ray spectrum with energy dispersion (EDX) from the matrix - Fig. 3, and its average chemical composition

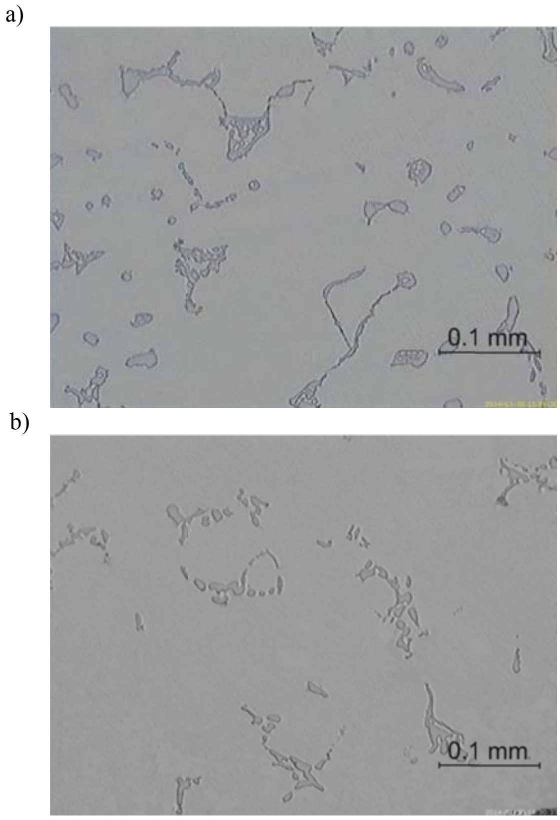


Fig. 6. Microstructure of the investigated cast steel after solutioning at : a) 1060°C, b) 1110°C; light microscope

The effect of the solution heat treatment temperature on the microstructure of the tested cast steel is best seen when the results obtained in the initial state and after solutioning at 1200°C are compared. It has been demonstrated that at this temperature, partial dissolution of the precipitates and their coagulation occur. As a consequence, after solutioning at 1200°C, the precipitates assume the form of local, compact aggregates (Fig.7). In the initial state, the volume fraction of the precipitates was 11%. For comparison, after the solution heat treatment, with the increasing temperature the decrease in the content of the precipitates was 8.5% (1060°C), 5.7% (1100°C) and 4% (1200°C). Chemical analysis of precipitates after the solution heat treatment at 1200°C showed that, compared to the initial state, the Si content was reduced to 6.6%, Ni to 18.4% and Mn to 1.2%. In contrast, the Cr content was observed to undergo a slight increase (Fig.8). The confirmed decrease in the silicon content by approx. 3.3% is responsible, among others, for the reduced microhardness of precipitates after the solution heat treatment at 1200°C (410 ÷450 μHV_{20}).

Chemical composition of the matrix of the tested material did not show any significant changes after the solution heat treatment compared with the initial state.

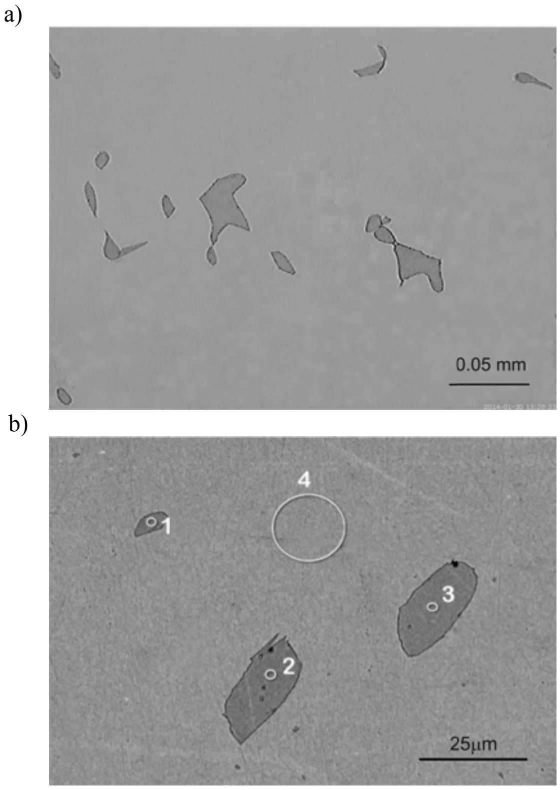
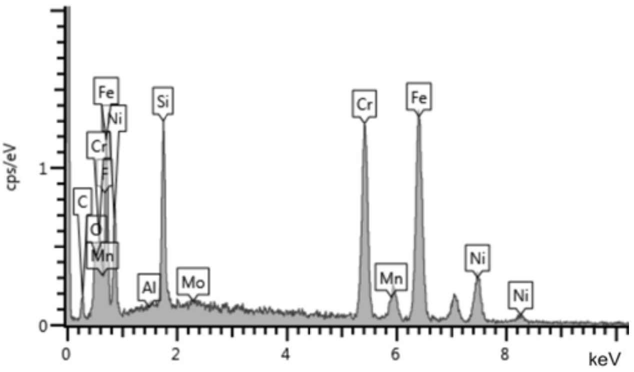


Fig.7. Microstructure of the investigated cast steel after solutioning at 1200°C, a) light microscope, b) SEM



Results of the EDX microanalysis of precipitate, wt.%					
Si	Cr	Ni	Mn	Mo	Fe
6.6	26.2	18.3	1.1	0.5	47.3

Fig. 8. X-ray spectrum with energy dispersion (EDX) from the precipitate - Fig. 8b, p.1, and its chemical composition

4. Conclusions

The microstructure of the cast 20%Cr-21%Ni-5%Si steel consists of an austenitic matrix and precipitates of different morphology distributed mainly on the grain boundaries. Compared to the matrix, the precipitates are enriched in Si, Cr, Ni and Mn.

The conducted heat treatment leads to a change in the morphology and chemical composition of the precipitates. With the increasing temperature of the solution heat treatment, the precipitates undergo partial dissolution and coagulation. At the same time, the content of Si, Ni and Mn decreases in these precipitates, while that of chromium slightly increases.

The volume fraction of the precipitates in the initial state was 11%. With an increase of the solution heat treatment temperature it dropped to 8.5%, 5.7% and 4%, respectively.

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