

ARCHIVES  
of  
FOUNDRY ENGINEERING



DOI: 10.2478/v10266-012-0111-0

ISSN (2299-2944)

Volume 12

Issue 4/2012

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

81 – 84

# Microstructure and Abrasive Wear Resistance of 18Cr-4Ni-2.5Mo Cast Steel

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Received 30.06.2012; accepted in revised form 03.09.2012

## Abstract

An influence of a decreased Cr content on the microstructure of the highly alloyed Cr-Ni cast steel, duplex type, melted under laboratory conditions, was characterized in the paper. The microstructure investigations were performed in the initial state and after the heat treatment (solution annealing) at 1060°C as well as the phase transformation kinetics at continuous cooling was measured. The wear resistance of the investigated cast steel was tested and compared with the 24%Cr-5%Ni-2.5%Mo cast steel.

The Cr content decrease, in ferritic-austenitic cast steels (duplex), from 24-26%Cr to 18% leads to the changes of the castings microstructure and eliminating of a brittle  $\sigma$  phase. In dependence of the casting cooling rate, apart from ferrite and austenite, also fine martensite precipitates occur in the casting structure. It was shown that the investigated cast steel is characterised by a slightly lower wear resistance than the typical cast steel duplex grades.

**Keywords:** Highly alloyed Cr-Ni cast steel, Microstructure, Equivalent Cr and Ni, CCT diagrams, Abrasive wear

## 1. Introduction

Corrosion resistant Cr-Ni cast steels are necessary materials applied for castings operating in several industry sectors [1, 2]. Within this group are cast steels of a ferritic-austenitic structure containing approximately: 24-26%Cr, 4-6%Ni and 2-3%Mo characterised by a high PREN coefficient, good corrosive resistance in environment containing chloride ions,  $Cl^-$ , and a creep limit twice as high as the one of traditional grades of austenitic cast steel [3-9]. This causes that more and more often austenitic cast steels are substituted by ferritic-austenitic cast steels, especially in case of complex conditions of castings operating [10-12].

In case of pump elements, where castings are subjected not only to corrosion but also to erosive influence of environment of their operation (e.g. transport of sludge and brines from coal mines), apart from a good corrosion resistance, an increased

resistance to abrasive wear is required. Taking into consideration high costs of castings from Cr-Ni cast steels, investigations were undertaken to examine the microstructure and abrasive wear resistance of cast steels characterised by a decreased Cr content in relation to the typical duplex steel of the second generation, and by the chemical composition corresponding to the duplex steel grade of the first generation 3RE60 (S31500; EN 1.4417) [5, 13].

## 2. Methods of investigation

Materials for examinations were melted in the laboratory induction furnace with using as charge material: armco iron, low-carbon Cr-Ni steel scrap, metallic Cr, Ni and Mo. The chemical composition of the melted cast steel is presented in Table 1. It corresponds to the first grade of high alloyed duplex steel, corrosion resistant (notation: 3RE60 acc. to ASTM A887).

Table 1.

The chemical composition of cast steel examined

Sign	C	Si	Mn	Cr	Ni	Mo	P	S	Cu	N
	% wt.									
A	0,02	0,3	1,0	18,3	3,8	2,3	0,009	0,019	0,05%Cu	0,04%N

Metallographic investigations of cast steels were performed by means of the light microscope Neophot 32 and electron scanning microscope, equipped with the EDS system of the IXRF Company for the X-ray microanalysis. The investigations of the cast steel microstructure were carried out in the initial state and after the heat treatment (solution annealing) at 1060°C. Investigations of phase transformation kinetics at continuous cooling from a temperature of 1100°C were made by using the dilatometer Adamel DT 1000. These investigations were used for drawing the CCT diagram.

The abrasive wear resistance of the investigated cast steel was carried out by 16-hours Miller' test [8]. Tests were performed in the mixture of SiC (grain size: 42.5-46.5µm) and water in proportion 1:1 [14]. After finishing investigations the abrasive wear intensity was determined by measuring the total sample mass loss. The surface assessment after 16-hours cycle was done by using the light microscope.

### 3. The obtained results and their discussion

The investigated cast steel is characterised by the PREN (Pitting Resistance Equivalent Number) coefficient = 26.7, which at the values of PREN<32, classifies this cast steel grade into the group of duplex steel with a small content of alloying additions, often marked with the LD symbol (Low Alloy Duplex Steels) [3]. On the basis of the chemical composition of the tested cast steel and equations known from the references [1, 2, 4] the equivalent Cr and Ni ( $Cr_{eq}=17.0$ ,  $Ni_{eq}=8.2$ ) were determined. Then using the Schaeffler's diagram, showing the influence of elements - stabilising ferrite and austenite - on the microstructure, it was preliminary determined that structural components of the tested cast steel are: ferrite, austenite and martensite.

Tests carried out by means of the light and scanning microscopes indicated that the microstructure of the investigated cast steel, in the initial state and after the heat treatment consists of the ferritic matrix and austenite 'islands' (Fig.1). It was also found that the austenite area is heterogeneous. At a higher magnification precipitates of another phase are seen in austenite areas. It is specially visible in microstructure images recorded by the scanning microscope (Fig.2).

The microanalysis performed of the ferritic matrix area and austenite 'islands' indicates, that the matrix was enriched in Cr and Mo while impoverished in Ni as compared to austenite (Fig.3, 4). Average results from the X-ray microanalysis are listed in Table 2.

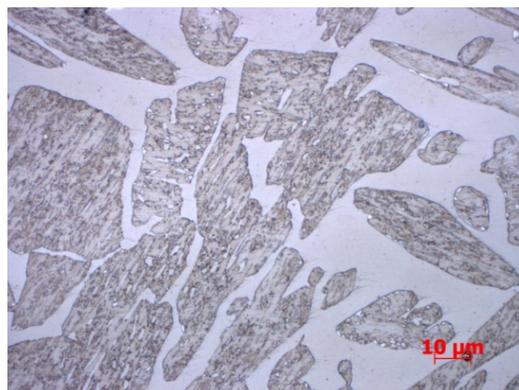
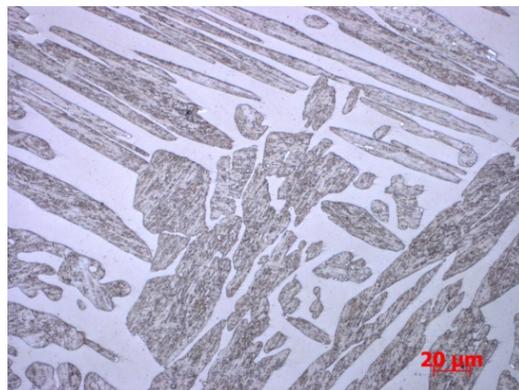


Fig. 1. Microstructure of the investigated cast steel after the heat treatment, light microscope

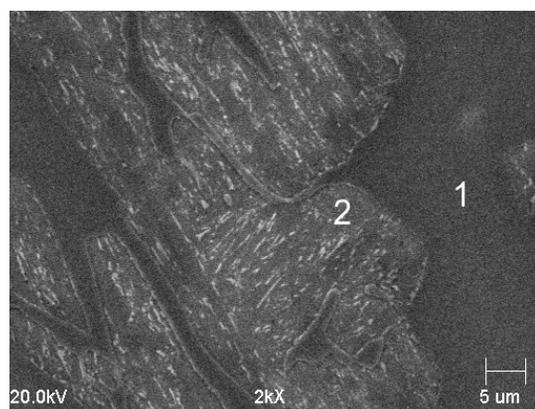


Fig. 2. Microstructure of the investigated cast steel, scanning microscope

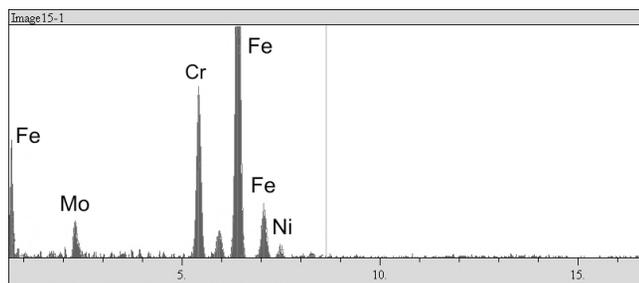


Fig. 3. X-ray spectrum with the energy dispersion (EDS) of the matrix area

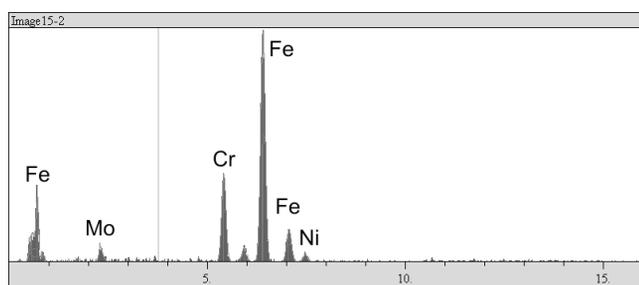


Fig. 4. X-ray spectrum with the energy dispersion (EDS) of the 'islands' area

Table 2.

Chemical composition of areas marked in Figure 2, the analysis area

Area of analysis	Cr	Ni	Mo	Si	Mn	Fe
	% wt.					
1	17,8	1,9	3,7	0,6	0,8	75,4
2	15,4	3,6	1,8	0,4	0,6	78,2

On account of the precipitates amount being in austenite and the lack of their analysing possibility by means of the scanning microscope as well as taking into consideration various cooling rates of castings dilatometric investigations were carried out. On the basis of the CCT diagram it was found that, at the application of a very slow cooling (below 0.33K/s), a distinct positive dilatation effect originated from the martensitic transformation occurs in the macrostructure of the investigated cast steel (Fig.5). This can confirm the presence of fine precipitates in austenite. Abrasive wear tests in the mixture of SiC and water (1:1) were performed for three grades of Cr-Ni cast steel (Fig.6). On the basis of the obtained results the relative summary mass loss of the investigated cast steels were determined and compared with the Cr-Ni cast steel containing increased amounts of Cr (up to 24% - marked C) and increased amounts of Cr (also up to 24%) and an addition of W (marked B). The investigated cast steel despite lower Cr content has only insignificantly smaller wear resistance, characterised by mass losses measured after 4, 8, 12 and 16 hours of the investigating cycle (Fig.6). The highly-alloyed Cr-Ni cast steel surface assessment carried out after finishing the wear tests indicates mainly the surface polishing effect. Also small plastic deformations of surfaces in a form of a few delicate scratches and defects, visible at magnification 100x, were found [15, 16]. On the one hand they are a result of the presence of hard SiC particles in the mixture and on the other hand this is related to a planetary motion occurring during abrasive wear tests.

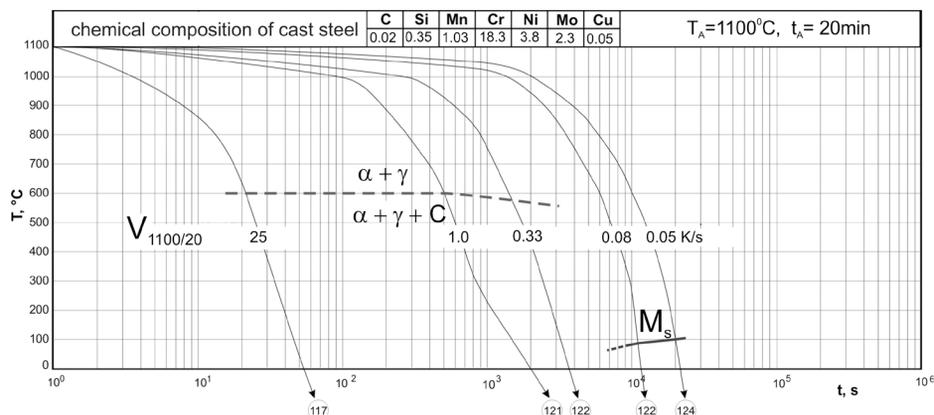


Fig. 5. CCT diagram of the investigated cast steel

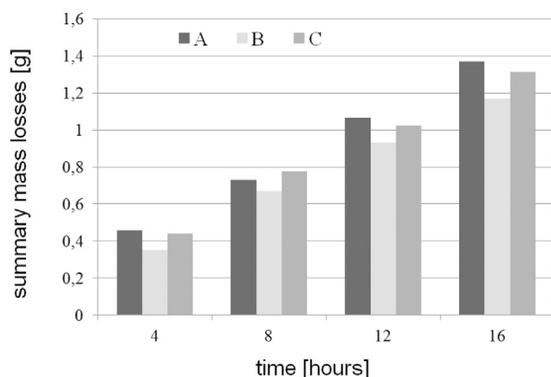


Fig. 6. Relative, summary mass losses for the investigated cast steel:

A – 0.02%C, 18.3%Cr, 3.8%Ni, 2.3%Mo,  
 B – 0.02%C, 24.0%Cr, 5.2%Ni, 2.5%Mo, 2.8%Cu, 1.2%W,  
 C – 0.02%C, 24.0%Cr, 5.2%Ni, 2.5%Mo, 2.8%Cu

## 4. Conclusions

- The investigated cast steel microstructure consists of the ferritic matrix, austenite islands and fine precipitates present in austenite.
- The analysis of the CCT diagram for the investigated cast steel indicates that at cooling rates smaller than 0.33K/s, ferrite, austenite and martensite will be present in the cast steel microstructure.
- The wear resistance tests of the investigated cast steel, performed in the mixture of SiC and water, indicate its lower resistance - in this environment - as compared to the cast steel of the Cr content increased to 24%.

## Acknowledgements

The research part of the study has been partially executed under a Statutory Work no 11.11.170.318 Task no.5 (2012).

## References

- [1] Baddoo, N.R. (2008). Stainless steel in construction: A review of research, applications, challenges and opportunities. *Journal of Constructional Steel Research*. 64, 1199-1206.
- [2] Baldew, R., Bhanu, K., Sahara, R., Jayakumar, T., Sivaprasad, P.V. & Savoja, S. (2009). *Advances in Stainless Steels*. Pshankar: CRC Press.
- [3] Sedriks, A.J. (1996). *Corrosion of Stainless Steels*, (2<sup>nd</sup> ed). New York, J.A Wiley and Sons.
- [4] Gunn, R.N. (1999). *Duplex Stainless Steels*. (2<sup>nd</sup> ed.). London-Cambridge: Woodhead Publishing Ltd.
- [5] PN-EN 10283 (2002)- Corrosion resistant steel castings.
- [6] ASTM A890/A890M – 10 (2003) Standard Specifications of Castings Fe-Cr-Ni-Mo, Duplex for General Application.
- [7] (2009). *Practical Guidelines for the Fabrication of Duplex Stainless Steel*. (2<sup>nd</sup> ed.). London: International Molybdenum Association (IMOA).
- [8] Lamb, S. (2001). *Handbook of Stainless Steel and Nickel Alloys*. Edmonton: CASTI Publishing Inc.
- [9] Kalandyk, B. (2011). *Characteristics of Microstructure and Properties of Castings Made from Ferritic-Austenitic Steel*. Katowice-Gliwice: Archives of Foundry Engineering. (in Polish).
- [10] Stradomski, Z. (2010). *Microstructure in Problems of Abrasion-Resisting Cast Steels*. Częstochowa: Wyd. Politechniki Częstochowskiej. (in Polish).
- [11] Stradomski, Z., Stachura, S., Dyja, D. & Zyska, A. (2006). Ferritic-austenitic cast steel – perspective and problems. *Hutnik - Wiadomości Hutnicze*. 5, 287-292. (in Polish).
- [12] Scientific-research program. AGH, Faculty of Foundry Engineering - directive of the POWEN-Wafapomp (2007-2008).
- [13] EN 10088-2,3. Stainless steels. Part 2 and 3.
- [14] Kalandyk, B. & Głownia, J. (2001). Estimate of mathematical model of weight losses kinetic in Miller apparatus. *Archives of Foundry Engineering*. 2 (4), 376-383. (in Polish).
- [15] Kalandyk, B. (2008). Wear resistance comparison of high alloyed Cr-Ni cast steel in SiC and water abrasive slurry. *Technologiczne Inżynierstwo*. 5 (2), 48-50. (in Polish).
- [16] Burakowski, T. & Wierzchoń, T. (1995). *Metal Surface Engineering*. Warszawa: WNT. (in Polish)