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CHARACTERISTICS OF LOW NICKEL FERRITIC-AUSTENITIC CORROSION RESISTANT CAST STEEL

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Preliminary Note – Prethodno priopćenje

The article presents the results of microscopic examinations of corrosion resistant cast steel with reduced nickel content obtained in a test casting with varying wall thickness. Investigations were carried out in as-cast condition and after heat treatment. Regardless of the casting wall thickness, increasing the manganese and nitrogen content to about 5 % and 2 500 ppm, respectively, yields the material with a two-phase microstructure containing ferrite in an amount of 55,6 ÷ 57,2 % (magnetic method) and 52,3 ÷ 55,2 % (analytical method). Based on the results of metallographic examinations, total elimination of the secondary austenite from the microstructure was observed. Microhardness measurements showed average values of 352,3 μHV_{20} and 267 μHV_{20} for the chromium ferrite and austenite, respectively.

Key words: duplex stainless cast steels, microstructure, nitrogen, mechanical properties

INTRODUCTION

The nitrogen is used as an alloying addition in duplex stainless steels. It increases the stability of austenite and ensures the growth of strength, improving also the resistance to pitting corrosion, which is characterised by a PREN (PREN = % Cr + 3,3 % Mo + 16 % N) [1-5]. The PREN for duplex stainless steels containing from 0,10 to 0,30 % N reaches a value of 32 ÷ 44 [1, 2]. The high content of nitrogen in materials of this type is associated with the high solubility of nitrogen in steels with an elevated addition of chromium. Manganese is another element increasing the solubility of nitrogen in steels [1, 3]. In austenitic steels resistant to corrosion this element, besides austenite stabilisation, can also improve the corrosion resistance in an atmosphere of carbon monoxide [6]. Therefore an attempt was made to partially replace Ni in cast ferritic–austenitic steels by increasing the content of Mn and N. Complete elimination of nickel from the cast steel is not cost-effective and is associated with a reduction of its toughness [1-3].

Considering the risk of the formation of blowhole defects in castings made of duplex stainless steels with an elevated nitrogen content, studies were carried out on a test casting with varying wall thickness.

MATERIALS AND METHODS

The examined cast steel was melted in a 30 kg capacity induction furnace. Nitrogen was introduced in the form of nitrogenated ferromanganese at the end of melting operation. The nitrogen content in the examined material was determined by LECO TN-14 analyser with an accuracy of ± 0,0002 wt %. The chemical composition of the cast steel is shown in Table 1. From the steel melt a step test block with the wall thickness of 14, 33 and 53 mm was cast. Metallographic examinations were carried out on a Neophot 32 microscope and by scanning electron microscopy. Tests were performed in as-cast condition and after heat treatment (solution treatment at 1 060 and 1 150 °C followed by cooling in water). Phase identification and quantitative analysis were performed on an EDAX X-ray energy dispersive analyser using metallographic sections etched with BWII reagents. The volume fraction of δ ferrite was measured by analytical and magnetic methods (ferrite measuring instrument MPD 100A). Hardness and microhardness of phases present in the examined material were also determined. Impact tests were carried out on a Charpy testing machine using "V" notched specimens.

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Table 1 **Chemical composition of Cr-Ni-Mn-N cast steel in experiments / wt %**

C	Si	Mn	Cr	Ni	N	Al
0,045	0,77	4,93	21,4	1,93	0,25	0,017
P= 0,019; S= 0,014						

DISCUSSION AND RESULTS

Macrostructural examinations of the cast step test block have shown the absence of any internal defects associated with the elevated nitrogen content, which in the examined cast steel reached the level of approximately 2 500 ppm, while the content of oxygen was 210 ppm.

Metallographic examinations of the melted cast steel have showed a ferritic-austenitic structure in both as-cast (Figure 1) condition and after heat treatment (Figure 2).

The results of measurements of the δ ferrite content are compared in Table 2. The content of ferrite in the examined cast steel is within the range recommended for cast duplex stainless steels. From the results obtained it follows that no significant differences in the amount of this phase have occurred with an increase in the casting wall thickness. Another aim of the studies was to determine the content of ferrite in a 14 mm thick casting wall at the solution treatment temperatures of 1 060 and 1 150 °C. The average content of ferrite was 55,0 % and 55,6 %, respectively.

The microhardness of as-cast ferritic matrix and of the austenite was 267 μHV_{20} and 352,3 μHV_{20}, respectively, and was independent of the casting wall thickness. The difference in as-cast microhardness of ferrite and austenite was 85,3 μHV_{20}.

Chemical analysis of ferrite and austenite, carried out for the examined material in as-cast condition and after solution heat treatment, has revealed an enrichment of ferrite with Cr and Si, and of austenite with Ni and Mn (Figure 3, Table 3). Both ferrite and austenite contained more than 20 % Cr.

Additionally, it was found that nitrogen has segregated to austenite, which is consistent with the data given in literature [2,7]. Dissolving into austenite, nitrogen improves the corrosion resistance, increasing also the strength characteristics of austenite, hardness included.

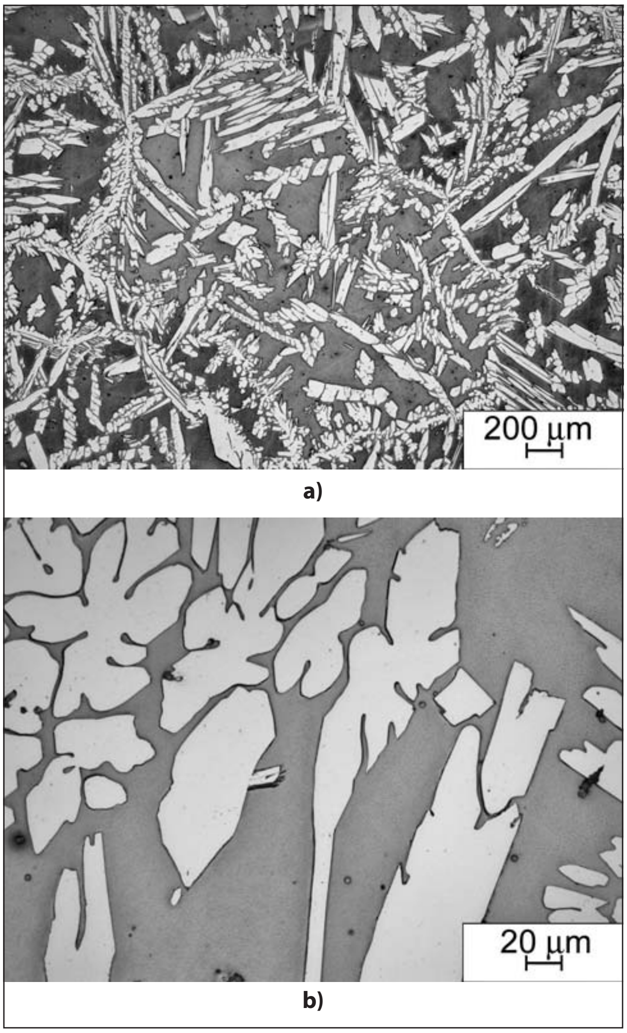

Figure 1 Microstructure of the investigated cast steel, wall thickness 33 mm; etchant - Bloech and Weld II, a) magn. 50x, b) magn. 500x

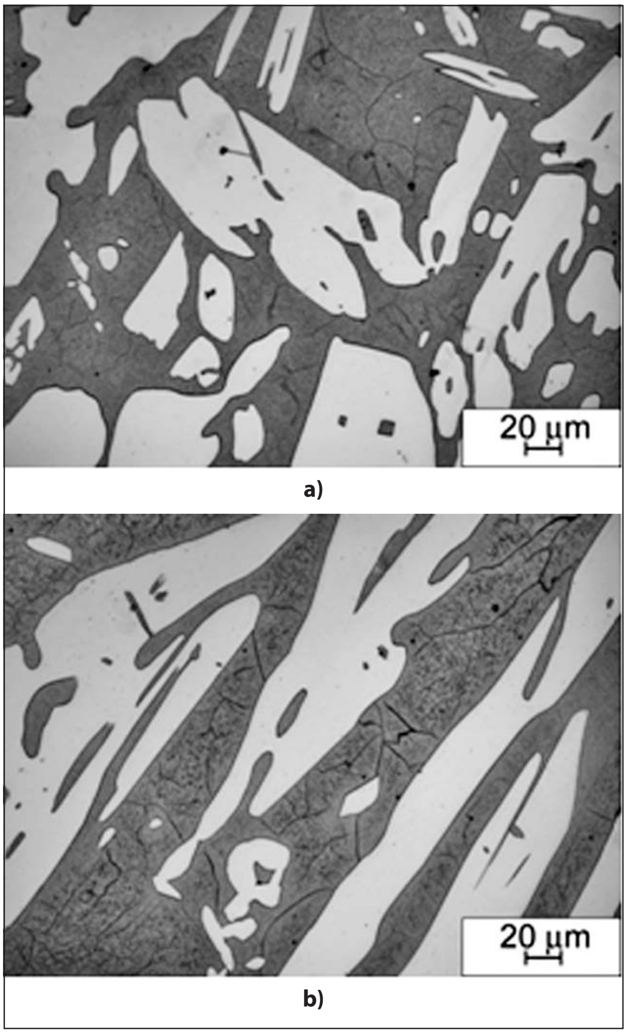

Figure 2 Microstructure of the investigated cast steel after the heat treatment at a) 1 060 °C and b) 1 150 °C, wall thickness 33 mm; etchant - Bloech and Weld II, magn. 500x

Table 2 **The average content of ferrite in investigated cast steel (in as cast condition)**

Wall thickness / mm	δ ferrite / %	
	Magnetic method	Analytical method
14	55,6	53,2 ± 0,08
33	56,6	55,2 ± 0,08
53	57,2	52,3 ± 0,08

Table 3 **Chemical composition of the ferrite and austenite / wt %**

Phase	Cr	Mn	Ni	Si	Fe
1- Austenite	20,1 21,3	4,5 5,1	1,1 1,7	0,8 1,8	Bal.
2- Ferrite	21,9 23,1	3,4 4,2	0,7 1,1	1,6 2,2	Bal.

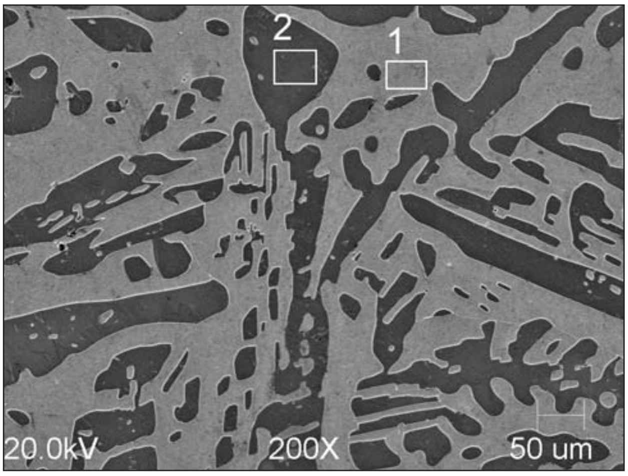

Figure 3 The SEM image of investigated cast steel, magn. 200x

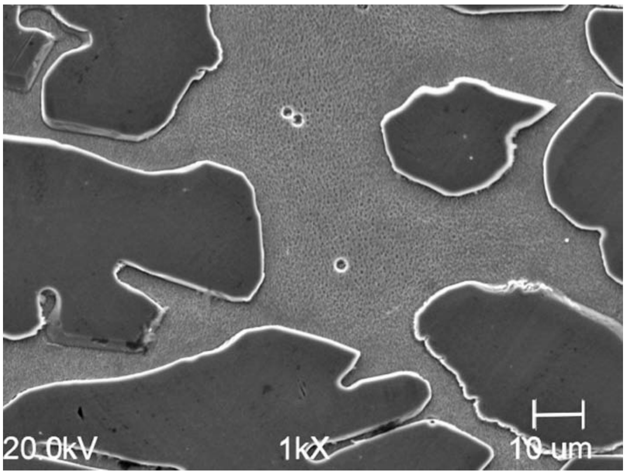

Figure 5 Microstructure of investgated cast steel after deep eatching, magn. 1 000x

The examinations of as-cast steel microstructure also revealed the presence of a few precipitates rich in Cr, which were probably chromium carbides (Figure 4). Carbon content, high as for the cast duplex steel (0,04 % C), might cause the precipitation of complex chromium carbides at the γ/α interface [2,4,5].

The analysis of cast steel microstructure deep-etched in a mixture of HNO_3 and HCl (2:1) indicates a higher dissolution rate of the matrix (Figure 5).

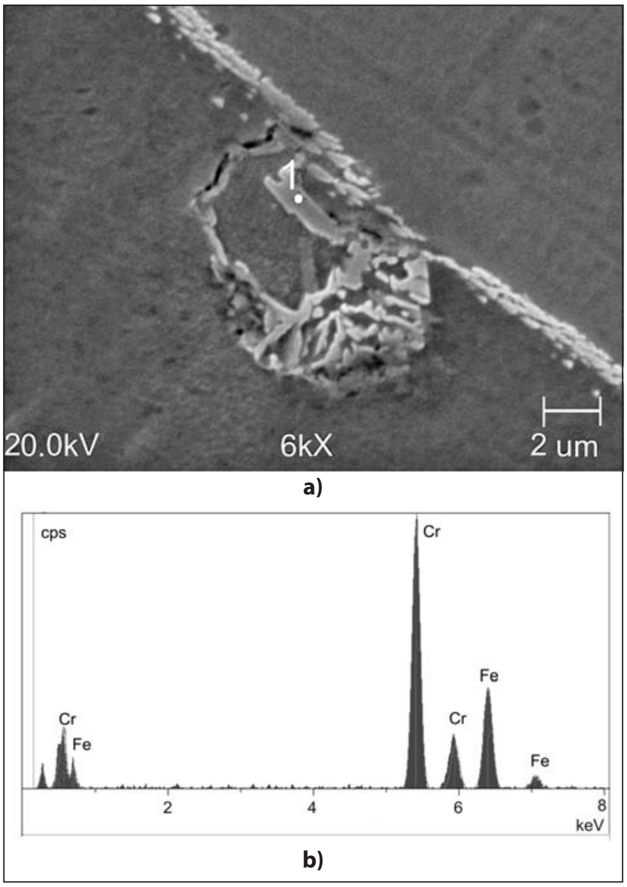

Figure 4 The Cr – enriched precipitates, a) SEM image, magn. 6 000x, b) X-ray spectrum with the energy dispersion (EDS) – from point 1

Impact strength of investigated cast steel

The impact tests were performed at ambient temperature on a Charpy testing machine using specimens cut out from the casting wall 33 mm thick. The results obtained were compared with a typical cast duplex steel (24Cr-5Ni-2,5Mo) and with the cast austenitic steel (19Cr-11Ni-2Mo). The test results are compiled in Table 4. Figure 6 shows a fracture of the examined material after the specimen rupture confirming its high toughness. Based on the results obtained, it has been concluded that impact strength of the examined cast steel is comparable with the cast austenitic steel 19Cr-11Ni-2Mo. As regards standard cast duplex steel (24Cr-5Ni-2,5Mo), a nearly double increase of this parameter has been obtained.

The specimens tested for impact properties were also used for hardness measurements (Table 4). Higher hardness of cast duplex steel compared with the cast austenitic steel is due to higher strength of the former material, which also makes it resistant to the abrasion and erosion wear [8,9].

Table 4 **Impact energy, impact strength and hardness of the investigated material and austenitic and duplex cast steels**

Material	Charpy energy / J	Average	
		KV / J/cm^2	Hardness / HB
21,5Cr-5Mn-2Ni-0,25N	122 126 126	155,8	236,8
24Cr-5Ni-2,5Mo	49 45 50	60,0	265
19Cr-11Ni-2Mo	108 126 117	146,2	233,5

CONCLUSIONS

– Introducing increased amounts of Mn and N to the cast corrosion resistant duplex steel with reduced Ni

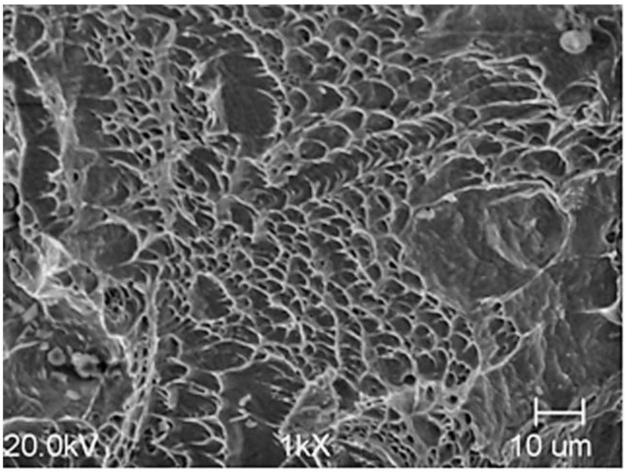

Figure 6 Fracture of the tested V-notched cast steel specimen, SEM image

content leads to the formation of a two-phase structure. The content of ferrite in the walls of the test casting amounted to about 55,6 ÷ 57,2 % as determined by magnetic methods and to about 52,3 ÷ 55,2 % as determined by the analytical method. Both ferrite and austenite contained more than 20 % Cr. Ferrite showed enrichment in Cr and Si, while austenite in Ni and Mn.

– The microhardness of ferrite and austenite was 267 μHV_{20} and 352 μHV_{20}, respectively, and it was independent of the casting wall thickness.
– In as-cast condition, the microstructure of cast steel was observed to include a few Cr-enriched precipitates detected at the γ/α interface. The precipitates were effectively eliminated by solution treatment already at 1 060 °C.
– The high content of N (2500 ppm) in the examined cast steel did not cause the occurrence of porosity defects in the walls of the casting.
– Higher levels of N and Mn added to the examined cast steel have increased its toughness compared to standard cast duplex steel.

Acknowledgements

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Note: The responsible translator for English language: "ANGOS" Translation Office, Kraków, Poland