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# Influence of carbon content on the segregation processes in duplex cast steel

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## Abstract

The paper aimed at determination of increased carbon content influence on segregation processes in a duplex ferritic-austenitic cast steel. The analysis of raw cast steel structure was carried out using a Zeiss Axiovert 25 optical microscope. The chemical composition of selected areas was examined using a JEOL JSM 5400 scanning microscope equipped with an EDX microanalyser and the obtained results were verified using the Thermo-Calc software.

The investigations carried out have shown that the lower carbon content causes the smaller amount of the intermetallic phases precipitates undesirable in the manufacturing process, which – affecting a clear deterioration in raw cast steel impact strength – promote origination of cracks in the castings. The increased, due to segregation processes, content of carbon, chromium and molybdenum within the solidification grain boundaries promotes precipitation of carbides already in the liquid state, what increases the propensity for hot cracking. The molybdenum content, in a cast steel of increased carbon content, varies from ~4% in the centre of solidification grain to ~6.5% in its boundary areas, and the chromium content from ~28% to 32%, respectively. Small enrichment of ferrite with molybdenum and chromium in boundary areas of cast steel solidification grains containing 0.02% carbon causes higher ferrite stability and prevents its decomposition in the temperature range from 600 to 900°C, what makes that the cast steel of lower carbon content features uniform ferritic-austenitic structure in as cast state.

**Keywords:** Casting Defect; Segregation; Sigma Phase; Carbides, Duplex Cast Steel.

## 1. Introduction

In numerous sectors of the industry it is necessary to use components, which are required to feature high resistance to corrosion and to erosion wear. Elements of pumps, most frequently subject to intensive action of erosion-corrosion medium, such as pumps casings and impellers, are manufactured as castings from alloy cast steels or cast irons. However, a strong corrosion attack of the medium narrows the range of cast irons use making that the share of high-alloy cast steels in the production of pumps operating in erosion-corrosion environments has been continuously increasing [1-5].

The materials price is one of basic parameters during their choice by designers, however, for many customers the Life Cycle Cost (LCC) is much more important, deciding about the actual costs of materials and taking into account also the components maintenance and replacement as well as the costs of shut-downs and of components repairs [6]. Continuous changes in prices of ferrochromium, ferromolybdenum and in particular of expensive nickel in the recent period, affecting the production costs and final product prices result in increase in interest in duplex steels and cast steels (DSS) [7]. Ferritic-austenitic cast steels feature a favourable high efficiency indicator determined by the LCC/price ratio, thanks to which prices of DSS components in the world markets are recently not subject to major changes at a parallel and clear increase in the price of components made of austenitic cast steels (Fig. 1) [8].

However, in the case of piece production of castings from duplex cast steels, with the use of induction furnaces, there is a risk of obtaining carbon content exceeding the value permissible for most grades, acc. to PN EN 100283:1998 equal $C_{max}$<0.03% [9].

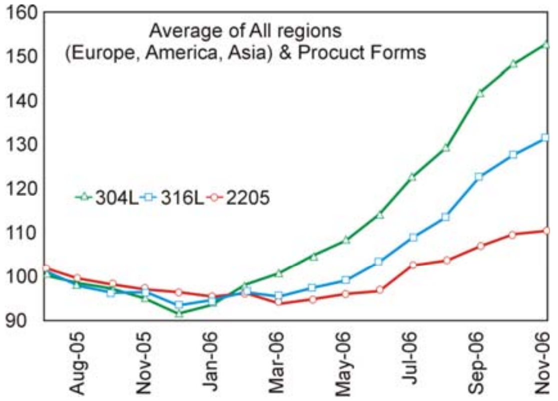

Fig. 1. Stainless steel enduser prices [8]

An increased carbon content in duplex cast steels does not substantially affect their corrosion resistance and the precipitating carbides do not create a major threat to the properties of steel. Chromium carbides originate in the δ/γ boundary, where carbon originates from the austenite and chromium from high-chromium ferrite, without depletion of interphase boundaries in this element. On the other hand, increased carbon content has a favourable influence on duplex cast steels erosion resistance, what is related to higher alloy hardness and a possibility of hard carbides and σ phase precipitation in the matrix [10,11].

However, an increased carbon content in duplex cast steels creates qualitative problems, connected both with the course of solidification and with processes occurring during casting's cooling in the solid state [12]. Segregation processes occurring during many hours of solidification of massive castings substantially affect the structure and technological properties of castings, in particular the propensity for hot cracking connected with precipitation of carbide eutectics and σ phase [13].

The influence of increased carbon content on segregation processes in a duplex ferritic-austenitic cast steel was examined in the paper.

## 2. Methodology and materials for research

The chemical composition of the duplex cast steel type GX2CrNiMoCu25-6-3-3 used for the present work is listed in table 1.

Table. 1.
The chemical composition of examined steel [%]

| C | Cr | Ni | Mo | Cu | Si | S | P | Mn |
|---|---|---|---|---|---|---|---|---|
| heat No. 1 | | | | | | | | |
| 0,028 | 24,20 | 8,82 | 2,30 | 0,02 | 0,85 | 0,010 | 0,011 | 0,46 |
| heat No. 2 | | | | | | | | |
| 0,055 | 24,40 | 6,71 | 2,40 | 3,08 | 0,81 | 0,020 | 0,020 | 0,14 |

The microscopic analysis of the cast steel in as-cast conditions was performed on a Zeiss Axiovert 25 optical microscope. In order to disclose the structure, the cast steel was chemically etched with reagent Mi21Fe (30g potassium ferricyanide + 30g potassium hydroxide + 60ml distilled water) that etches ferrite δ and the σ phase which is visible as a dark phase in the microscopic image. The analysis of chemical composition of selected micro-regions was carried out using a JEOL JSM 5400 scanning microscope equipped with an EDX microanalyzer. The verification of the metallographic examination results was done using the Thermo-Calc program.

## 3. Results and discussion

Examinations of raw cast steel castings structure have shown that with decreasing carbon content the amount of unfavourable intermetallic phases precipitates goes down. Those precipitates, creating a characteristic network at the boundaries of primary solidification grains (Fig. 2b), substantially deteriorate the impact strength of raw cast steel, which for a cast steel containing 0.05% C amounted to only 7J. A cast steel with 0.02% carbon features homogeneous ferritic-austenitic structure (Fig. 2a) ensuring a high, ~60J, impact strength in the as-cast state.

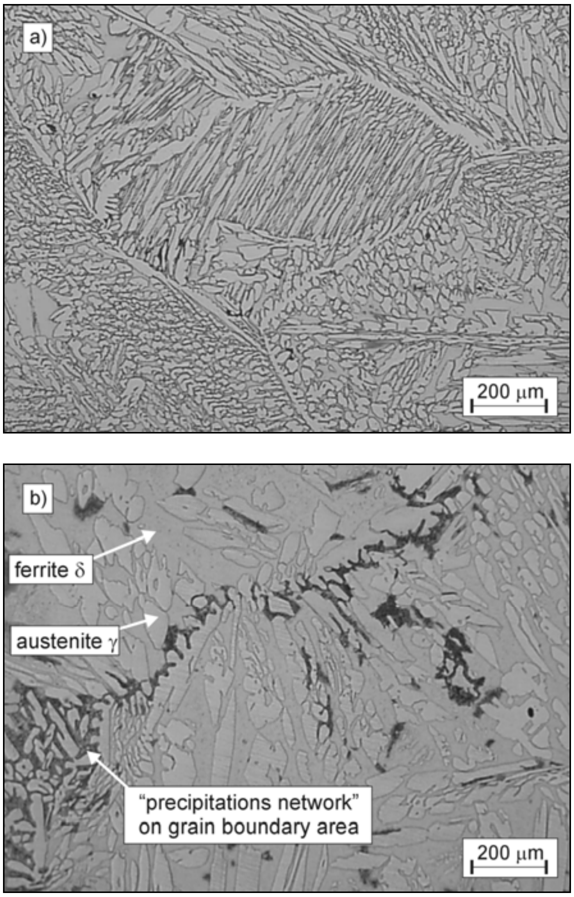

Fig. 2. The microstructure of investigated cast steel in as-cast conditions: a) heat No. 1, b) heat No. 2.

The analysis of microstructure of solidification grains' boundary areas of cast steel from heat 2 has shown that they are privileged places for carbides and intermetallic σ phase precipitation (Fig. 3) during solidification and cooling afterwards. Diversified structure after solidification and adverse changes occurring during casting's cooling make that micro-areas with precipitated brittle phases, in particular σ phase, are favourable to cracks origination in castings, what has been described at length in authors' paper [14].

Results of EDS examinations of carbide formers content in ferrite in the centre of a solidification grain and on its boundary areas show that carbon promotes segregation of elements, in particular molybdenum and chromium (Tab. 2). The molybdenum content, in a cast steel of increased carbon content, varies from ~4% in the centre of solidification grain to ~6.5% in its boundary areas, and the chromium content from ~28% to 32%, respectively. So high content of alloying elements and carbon makes that carbides can precipitate already from the liquid phase.

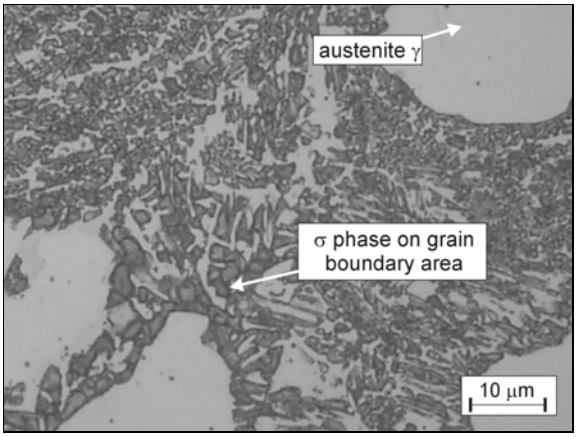

Fig. 3. Occurrence of σ phase on the grain boundary regions, cast steel in as-cast conditions, heat No. 2

Table. 2.
The result of EDS examination of the contents of alloying elements in the ferrite

| | within the solidification grain | | | on the grain boundaries of solidification grain | | |
|---|---|---|---|---|---|---|
| | $x_{max}$ | $x_{min}$ | $x_{śr.}$ | $x_{max}$ | $x_{min}$ | $x_{śr.}$ |
| | heat No. 1 | | | | | |
| Cr | 28,87 | 27,45 | 28,1 | 28,78 | 27,83 | 28,4 |
| Mo | 4,10 | 3,58 | 3,88 | 4,28 | 4,02 | 4,15 |
| Fe | 61,5 | 60,5 | 61,0 | 60,0 | 55,9 | 57,3 |
| | heat No. 2 | | | | | |
| Cr | 28,6 | 27,8 | 28,0 | 34,1 | 29,1 | 32,0 |
| Mo | 4,18 | 3,64 | 3,91 | 7,40 | 3,59 | 6,40 |
| Fe | 61,6 | 60,4 | 61,0 | 60,2 | 55,7 | 57,3 |

The ferrite, during slow cooling after solidification, in the boundary areas of grains highly enriched with Cr and Mo (elements promoting origination of the σ phase) is subject to eutectoid decomposition into the sigma phase and austenite. As the analysis of microstructure shows, the cracking proceeds just across eutectoid areas, what has been described at length in paper [15].

For the cast steel containing 0.02% of carbon (heat No. 1) no clear segregation of alloying elements to solidification grains boundaries was found. Slight enrichment of ferrite with molybdenum and chromium in solidification grain boundary areas (Tab. 2) results in its higher stability and prevents ferrite decomposition between 600 and 900°C according to the δ → σ + γ' reaction. This makes that the cast steel of lower carbon content featuring homogeneous ferritic-austenitic structure is fit for manufacturing of complex castings without the risk of cracking.

To verify the ferrite microstructure examinations and chemical composition analyses carried out, non-equilibrium solidification was simulated using the Thermo-Calc software and the results are shown in Fig. 4.

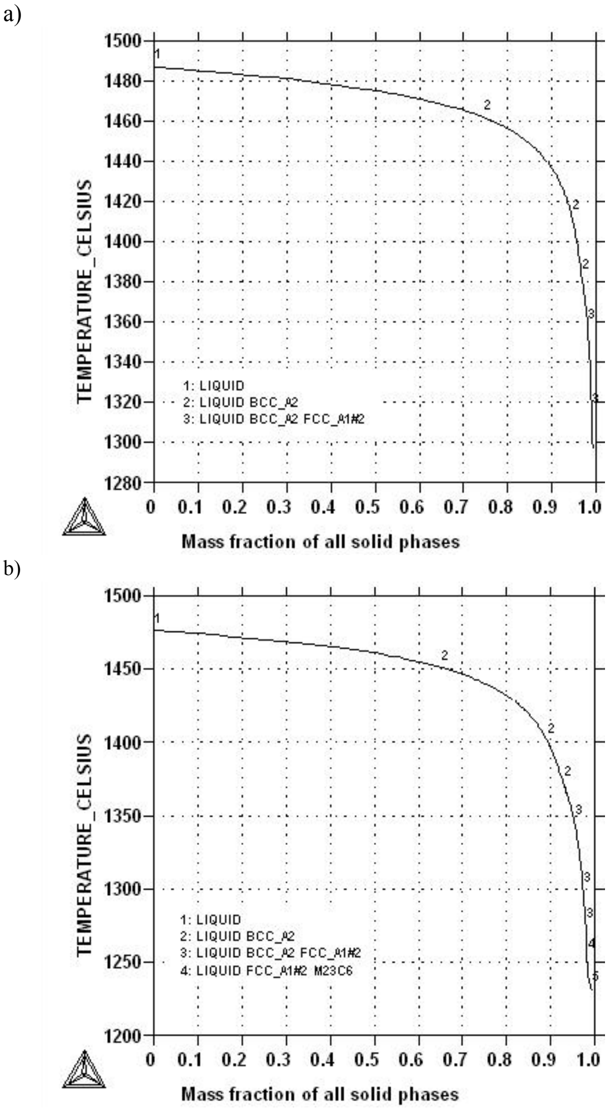

Fig. 4. Non-equilibrium solidification analysis, Thermo-Calc

It has been shown that a slight enrichment with carbon, chromium and molybdenum of primary grain boundary areas causes these areas to solidify as ferritic, and a peritectic reaction occurs only after solidification of ~98% of ferrite. In the case of enriching the solidification grain boundary areas with carbon, chromium and molybdenum there is a possibility of peritectic reaction occurrence after solidification of 95% of ferrite and of carbides precipitation already in the liquid state (Fig. 4b).

## 4. Conclusions

The examinations carried out allow formulating the following statements and conclusions

- the quantity of intermetallic phases precipitating during the manufacturing process goes down with decreasing carbon content. These precipitates, causing a clear deterioration in raw cast steel impact strength, promote origination of cracks in castings,
- for duplex cast steels it is necessary to guarantee a low carbon content as it increases the propensity for cracking of massive castings. The increased, due to segregation processes, content of carbon, chromium and molybdenum within the solidification grain boundaries makes that carbides can precipitate already in the liquid state, what increases the propensity for hot cracking. The molybdenum content, in a cast steel of increased carbon content, varies from ~4% in the centre of solidification grain to ~6.5% in its boundary areas, and the chromium content from ~28% to 32%, respectively,
- the cast steel containing 0.02% of carbon does not show clear segregation of alloying elements to solidification grains boundaries. Small enrichment of ferrite with molybdenum and chromium in boundary areas of solidification grains causes higher ferrite stability and prevents its decomposition in the temperature range from 600 to 900°C, what makes that the cast steel of lower carbon content features homogeneous ferritic-austenitic structure in as cast state.

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