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SEGREGATION OF ELEMENTS IN CORROSION RESISTANT CASTINGS OF DIVERSIFIED WALL THICKNESS

SEGREGACJA PIERWIASTKÓW W ODLEWACH KWASOODPORNYCH O ZRÓŻNICOWANYCH GRUBOŚCIACH ŚCIANEK

The segregation of elements in two corrosion resistant cast steel grades Cr18-Ni9-Mo, in castings of wall thickness: 7, 15 and 30 mm were performed. The results indicate the analogous path of curves of the content of Fe, Cr, Ni, Mo and C, in walls of various thickness. Decrease in the content observed in the delta ferrite Fe (2 to 3 wt. %), Ni (from 3.5 to 5 wt. %) and C (about 1 wt. %), where the Mo and Cr increased their content of 2% wt. %, and about 6% wt. respectively in the case of the two test cast. For the test steel Q2 with a carbon content 0.054 wt. % were found carbides in the form of white precipitates on the grain boundary of delta ferrite. This resulted in the occurrence of the peaks in the lines of the element distribution analysis especially for molybdenum, iron and carbon, as shown in the diagrams for various segregation of wall thickness.

Keywords: segregation of elements, stainless steel, ferrite, carbides

Zbadano segregację pierwiastków w dwóch gatunkach staliwa kwasoodpornego Cr18-Ni9-Mo, bezpośrednio w odlewach o grubościach ścianek 7, 15 i 30 mm. Wyniki wskazują, analogiczny przebieg krzywych zawartości Fe, Cr, Ni, Mo i C, zebranych w różnych grubościach ścianek. Spadek zawartości odnotowano w ferrycie delta dla Fe (od 2 do 3% wag.), Ni (od 3,5 do 5% wag.) oraz C (około 1%), natomiast w przypadku Mo oraz Cr stwierdzono wzrost zawartości o odpowiednio 2% wag. i około 6% wag., w przypadku dwóch badanych staliw. Dla badanego staliwa Q1 o zawartości węgla 0,054% wag. stwierdzono występowanie węglików w postaci białych wydzieleń na granicy ferrytu delta. Spowodowało to występowanie pików na linii analizy rozkładu pierwiastków zwłaszcza dla molibdenu, żelaza oraz węgla, co zostało uwidocznione na wykresach segregacji dla różnych grubości ścianek.

1. Introduction

Steels and cast steels containing from 15 to 25% of chromium and from 8 to 11% of nickel (with addition of 2% of molybdenum) are valued in several industrial sectors, due to their good resistance to chloride ions, sea water, acids (acetic and sulphuric), as well as the stress and pitting corrosion resistance. Therefore they are used for castings of pump elements (rotors, guide rings, casings), applied in industries: chemical, marine or mining [1-3]. Microstructures of these corrosion resistant cast steel consist of austenite and – in dependence of the ratio of the ferrite- to austenite-forming elements – of a certain amount of ferrite delta (from 5 to 40%) [4]. However, in as-cast condition state also carbides and brittle phases can occur (σ, α‘)[4]. This specially concerns shaped castings of variable wall thickness, since a microstructure heterogeneity, presence of carbides or TCP phases, leads to stresses in wall joints and then to cracks. Therefore the knowledge of the segregation and tendency to brittle phases occurrence is essential for foundry engineers and for castings users. Segregation processes in these cast steel grades were investigated several times [5,6], especially on grain boundaries [6,7]. Usually the segregation of C, Cr, Fe, Ni were investigated on grain boundaries while distribution of carbides, carbonitrides, or contamination changes (e.g. phosphorus) in matrixes and along grain boundaries [7]. The segregation processes of basic elements and those, which are added in the metallurgical process (e.g. Al), were compared for three casting walls of a different thickness (7, 15 and 30 mm). This allows to predict defects in these places of the casting, in which the segregation constitutes a real problem. Differences in carbon, chromium and molybdenum content cause often such problems in acid resistant cast steels.

2. Methodology of investigations

Two chromium-nickel-molybdenum cast steels were selected for investigations of the segregation of elements. The chemical composition of these cast steels are given in Table 1. The first stage of testing comprised making castings of the pump rotor segments, which are elements of the industrial pump rotor, Fig. 1. The melts were performed in the induction furnace of a capacity of 30 kg and basic lining. Castings of a mass of 2.8 kg have diversified wall thickness and in three of them of a thickness: 7, 15 and 30 mm (Fig. 1), the segregation was measured.

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TABLE 1

Chemical composition of the tested cast steels

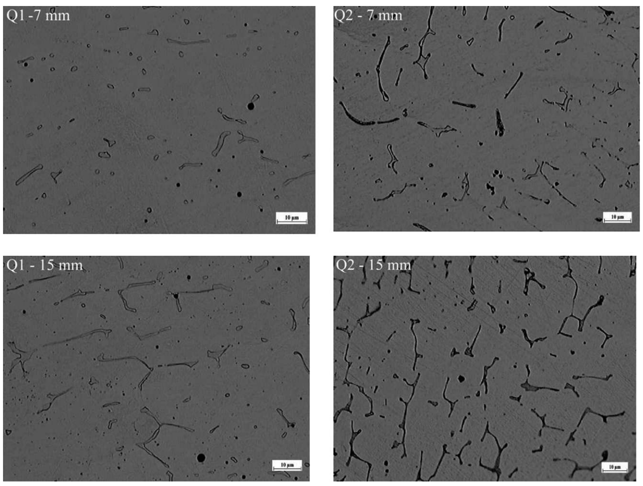
Sample designation	Chemical composition [wt. %]										
	C	Si	Mn	P	S	Cr	Mo	Ni	Al	Co	Cu
Q 1	0.024	0.59	1.49	0.038	0.006	17.04	1.01	8.91	0.006	0.14	0.35
Q 2	0.054	0.34	0.62	0.034	0.003	17.57	2.04	9.71	0.029	0.14	0.31

Fig. 1. Casting of a pump rotor segment

3. The obtained results and their analysis

In the initial state of investigations the microstructure of samples in as-cast condition was tested. In order to do this, the metallographic microsections were prepared and etched in solution containing 1 part of HNO_3 and 2 parts of H_2SO_4. Microstructure analysis was done by means of the metallographic microscope Neophot 32, showing the microstructure consisting of austenite with ferrite delta and a certain amount of non-metallic inclusions Fig. 2.

The segregation of 11 different elements was made – in three walls of various thickness of the casting of the pump rotor segments – by means of the scanning electron microscope QUANTA 3D FEG of the FEI Company, equipped with the energy dispersive spectroscope of X-ray radiation Genesis 4000 of the EDAX Company.



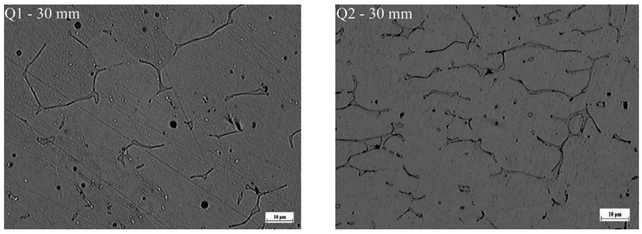


Fig. 2. Microstructures of cast steel Q1 and cast steel Q2 magnification 1000x

As it is seen in Fig. 2a and Fig. 3, in cast steel Cr18-Ni9-Mo1, containing small amounts of carbon (0.024 wt. %), in walls of three tested thickness the microstructure consists of austenite and small amounts of δFe. Carbides were not observed.

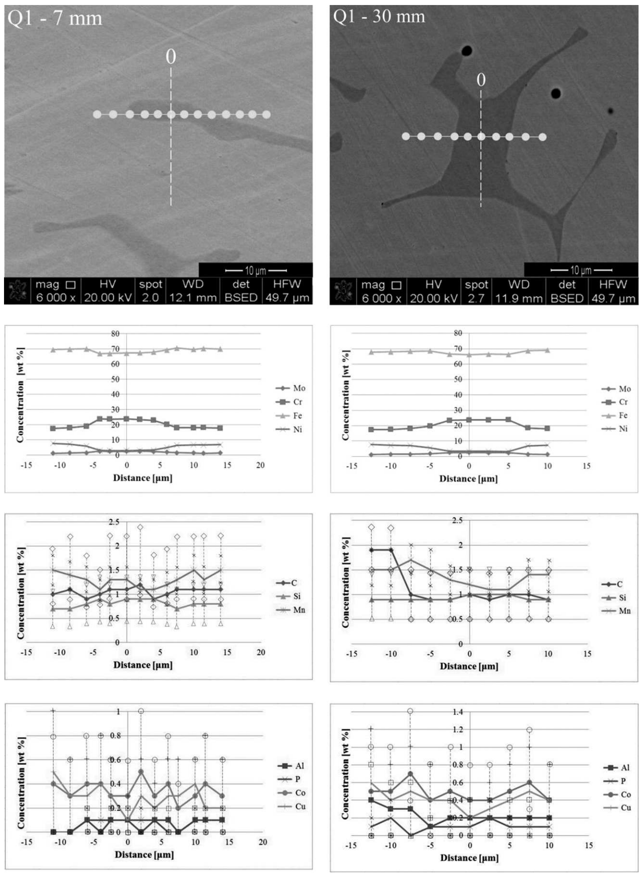


Fig. 3. Segregation of elements in the alloy marked as Q1; wall thickness 7 and 30 mm

Diagrams of the elements segregation in cast steel Q1 are presented in Figure 3. The iron content decreases by app. 3 wt. % and nickel by app. 2 wt. % in ferrite delta. Instead, the chromium content increases by 5 wt. % and molybdenum by more than 1 wt. %. In a further analysis the content of C, Al and P increases by app. 0.1 wt. %. Mn and Cu decrease their content by maximum 0.4 wt. %, while Co demonstrates high divergences (0.2 wt. %) on the whole segregation line. The segregation process path in cast steel Q1 of a wall thickness 15 mm is similar to the process when a wall thickness is 7 mm.

The analysis of the segregation in cast steel Q1 of a wall thickness 30 mm indicates the insignificant heterogeneity of austenite in point 3, being 2.5 μm in front of its boundary with ferrite. The carbon content decreases by 0.9 wt. % and phosphorus content by 0.2 wt. % within this zone. The content of Mn, Co and Cu increases insignificantly. Apart from that, the segregation process of elements in this wall thickness is very similar to this process in other walls.

Cast steel Q2 (of a chemical composition given in Table 1) differs mainly by the content of carbon, chromium, nickel and molybdenum. These differences are significant specially in the carbon and molybdenum content. To that effect, at a carbon content of 0.054 wt. % carbides were found – in all walls – on the boundary: ferrite delta-austenite, Fig 4. They form point precipitates as well as a continuous lattice around ferrite δ, especially for walls 30 mm thick, Fig. 4.

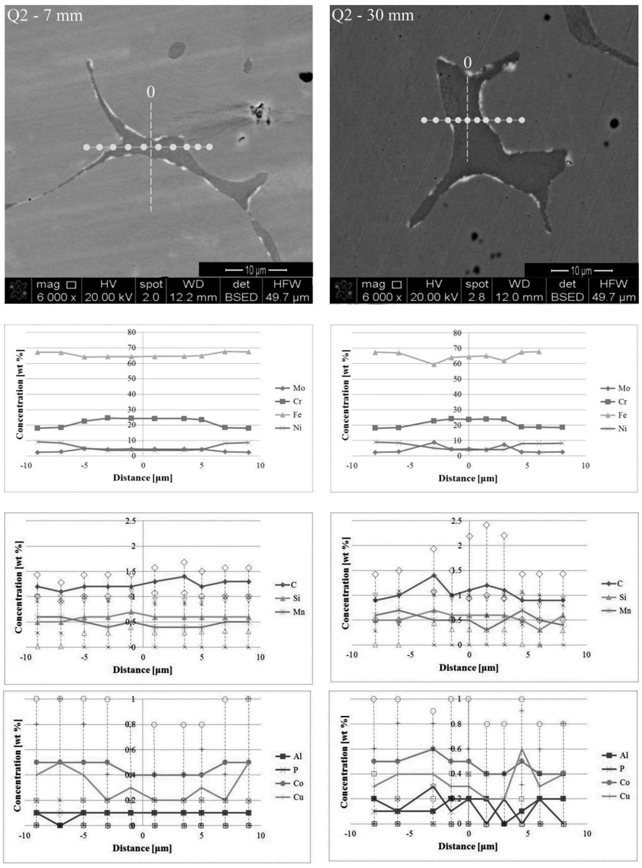


Fig. 4. Segregation of elements in the alloy marked as Q1; wall thickness 7 and 30 mm

The second important effect of the influence of the wall thickness is the segregation degree. The segregation pathways of iron, molybdenum and carbon are not the same in all wall thickness. This is caused by carbides discontinuous precipitation on the boundary: austenite-ferrite, regardless of the chemical composition of cast steel (Q1 or Q2), Fig. 5 and Fig. 6. The segregation of chromium, molybdenum and nickel (Fig. 5) does not depend of the wall thickness in cast steels of a low carbon content. In accordance with the known tendency [4], ferrite forming elements segregate into ferrite delta. It should be emphasized that the chromium concentration increases from 18 to 24 wt. % in δFe, and molybdenum from 1.2 to 2.5 wt. %, while the nickel concentration decreases from 7.5-8 wt. % in austenite to 3-3.5 wt. % in δFe, Fig. 5. The visible influence of the wall thickness on the iron concentration results also from the segregation of other elements (silicon, manganese, cobalt, Fig. 4).

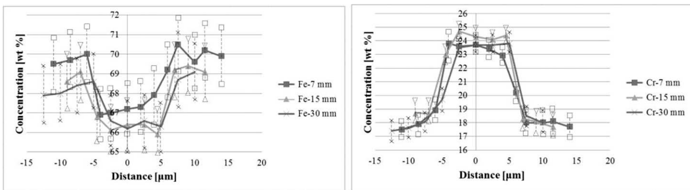


Fig. 5. Diagrams of iron and chromium segregation in various casting walls (Q1 alloy)

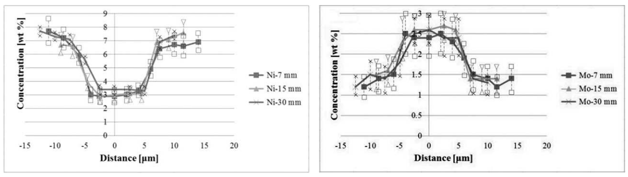


Fig. 6. Diagrams of nickel and molybdenum segregation in various casting walls (Q1 alloy)

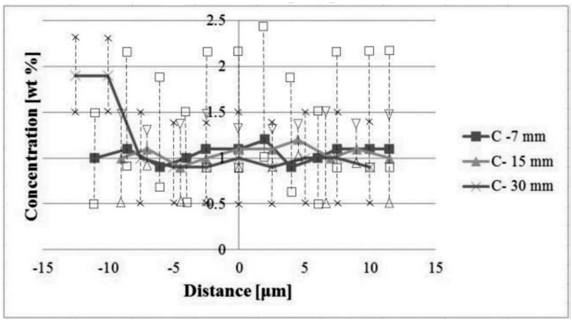


Fig. 7. Diagrams of carbon segregation in various casting walls (Q1 alloy)

The increased carbon content to 0.054% leads not only to precipitates of carbides, but also to changing the segregation of some elements. In a similar fashion as for the previously discussed cast steel (0.024 wt. % C), both chromium and nickel indicate the constant content in ferrite δ, it means: 25 wt. % Cr and 3 wt. % Ni, regardless of the wall thickness. But e.g. molybdenum has a tendency to increasing its content to δFe, however before the precipitation of δFe its concentration is higher (even to 9%, Fig. 9). This effect is visible, especially for wall thickness 15 and 30 mm.

Iron behaves the other way round, Fig. 6. Its content decreases to δFe, but before its precipitation it decreases even more. Here, the influence of the wall thickness is distinct.

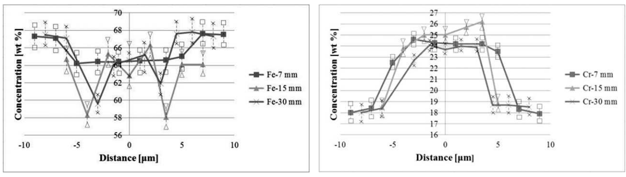


Fig. 8. Diagrams of iron and chromium segregation in various casting walls

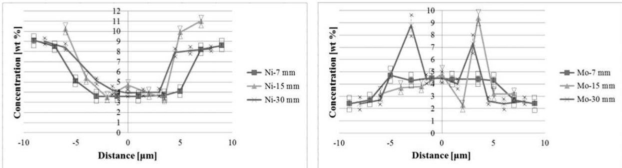


Fig. 9. Diagrams of nickel and molybdenum segregation in various casting walls

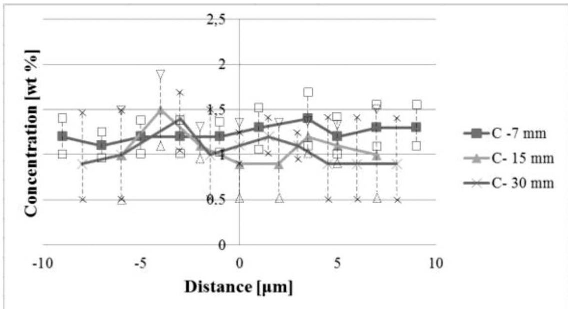


Fig. 10. Diagrams of carbon segregation in various casting walls

4. Conclusions

1. The performed analysis of the elements segregation in walls of the casting of the pump rotor segment indicates, that in the cast steel containing 0.024 wt. % C (Q1) carbides do not occur neither on grain boundaries nor interface boundaries austenite-δ Fe. The distribution pathways of elements in walls 7, 15 and 30 mm thick have similar arrangements and sometimes lines of elements values nearly overlap.
2. Carbides on ferrite delta boundaries, in cast steel containing 0.054 wt. %C were observed in all tested thickness of the walls. In the wall 15 mm thick precipitates of carbide were also noticed in the middle of ferrite islands, which caused the peaks formation in points in which carbides were analysed, due to which large fluctuations of elements values were obtained.
3. The distribution of Fe, Cr, Ni, Mo and C content in various walls of cast steel, Q2, indicated that for Cr and Ni the path was analogous in all thickness of walls. Large content changes were observed for the remaining elements on the ferrite island boundaries, caused by carbide occurrence. Very high carbon contents in the results showed at Fig. 4÷10 are connected with it contamination on the surface investigated samples.

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