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SOLIDIFICATION STRUCTURE OF MASSIVE CASTINGS FROM DUPLEX CAST STEEL

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SUMMARY

Problems related with duplex massive cast production are presented in this work. Macro and microstructure investigations of GX2CrNiMoCu25-6-3-3 cast steel after solidification were done. The influence of cooling rates and segregation on intermetallic phases formation, especially sigma phase, were shown. The segregation process and cooling rates during solidification have great influence on intermetallic phases formation. Sigma phase occurrence in the cast structure causes deterioration of technological and functional properties.

Keywords : duplex cast steel, solidification, sigma phase, segregation

1. INTRODUCTION

Requirements of duplex cast steel users are concentrated on precise selection of chemical composition and mechanical properties. Structure, shape of inclusions, their dimensions and distributions, or solidification structure defects like a contraction cavity are specified rarely or even at all. These factors have often a greater influence on technological and mechanical properties of casts than small differences in the chemical composition. Mechanical properties and corrosion resistance of the duplex cast steel are related with austenite and ferrite structures, their morphology and grain size, morphology and distribution of carbides, nitrides and intermetallic phase series, which influence is often adverse.

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Goods mechanical properties and erosion–corrosion resistance of duplex stainless steel had an influence on national power and extractive industry interests, for such applications as pump rotors, turbine blades or pipe elements.

Technological problems related with susceptibility to cracking of massive casts, caused that the authors of this publication cooperate with one of the largest Polish cast steel foundry in production of casts from this material.

2. INVESTIGATED MATERIAL

Investigated material was taken from the massive cast of pump rotor designed for work in temperature 45-70^{0}C, in environment of liquid solutions, with variable pH=4÷7, heavily polluted with solid state particles such as: $CaSO_4$~ 95%, $CaSO_3$, $CaCO_3$ and magnesium compounds. Cracked casting in as-cast condition was investigated.

Table 1. The chemical composition of GX2CrNiMoCu25-6-3-3 cast steel
Tabela 1. Skład chemiczny staliwa GX2CrNiMoCu25-6-3-3

Element	**C**	**Cr**	**Ni**	**Cu**	**S**	**Si**	**Mn**	**P**	**Mo**	**Co**
[%]	0,06	24,2	7,5	2,6	0,01	0,9	0,13	0,02	2,41	0,02

Obtained material permitted for precise analysis of the massive cast solidified structure. Many works performed in Poland have applied to small-mass laboratory produced materials. Authors examinations compared with the implementation of massive, a few tones in weight, duplex casts, show the great problems related with cracking of the elements from this material. Possibility of production in Polish foundries casts with a low (<0,03%) carbon content, specified in PN-EN 100088-1:1998 is also very difficult.

3. THE ANALYSIS AND DESCRIPTION OF STAINLESS STEEL STRUCTURE

The results of Hammar and Swensson investigations were shown in the work [2]. They examined the influence of the chemical composition on the way of the duplex cast steel solidification. They determined the empirical relationship of parameter ϕ (1) and its value for the different solidification conditions.

$$\phi = Ni_{eq} - 0{,}75Cr_{eq} + 0{,}257 \quad (1)$$

$$Cr_{eq} = Cr + 1{,}37Mo + 1{,}5Si + 2\,Nb + 3Ti$$

$$Ni_{eq} = Ni + 0{,}31Mn + 22\,C + 14{,}2N + Cu$$

It can be obtained, using the parameter value, that the GX2CrNiMoCu25-6-3-3 cast steel solidifies completely as ferrite. The continuation of cooling causes the

ferrite→austenite transformation, but proportion of these two phases in the room temperature is connected with the cooling rate and alloying additions. If the cooling rate of the cast after the solidification is higher, the ferrite-austenite transformation is slowed down, so the larger amount of the ferrite can be obtained in the ambient temperature. Changes in the cast structure during the solidification and continuation of cooling after the solidification have negative effect on the technological properties. The main factors which have an influence on deterioration of these properties are:
- segregation of the chemical composition
- carbides precipitation
- creation of hard and brittle sigma phase

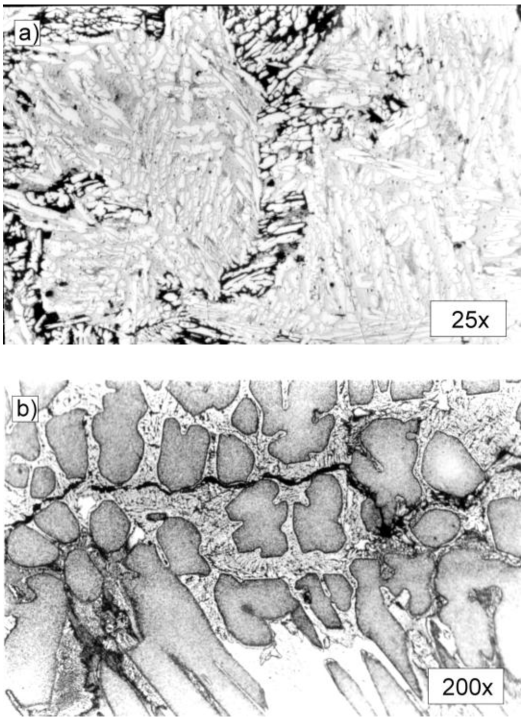

Fig. 1. The ferritic-austenitic microstructure of GX2CrNiMoCu25-6-3-3 cast steel
Rys. 1. Ferrytyczno-austenityczna struktura staliwa GX2CrNiMoCu25-6-3-3

The cast microstructure of as-cast condition is showed in Figure 1. It can be observed that the long time of the solidification causes the origination of large “solidification grains” surrounded by the network of the more intensely etched structure. The structure observed in the area of primary ferrite grains boundaries enriched in intensely segregating impurities and the alloying elements, mainly consisted of austenite, sigma phase and a small amount of carbides. The experimental data show that the initiation and propagation of cracks is observed in the area of the structure around the large solidification grains (Figure 1b). The main reason of intercrystalline cracks formation in as-cast steel is the hard and brittle sigma phase and carbides in this area (Figure 2 and 3).

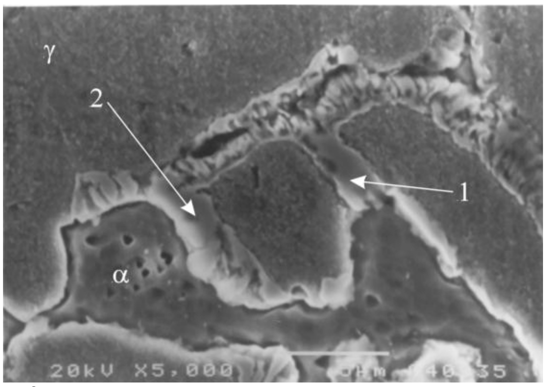

Fig. 2. The ferritic-austenitic microstructure with carbides on grain boundaries
Rys. 2. Struktura ferrytyczno-austenityczna z węglikami na granicach ziaren

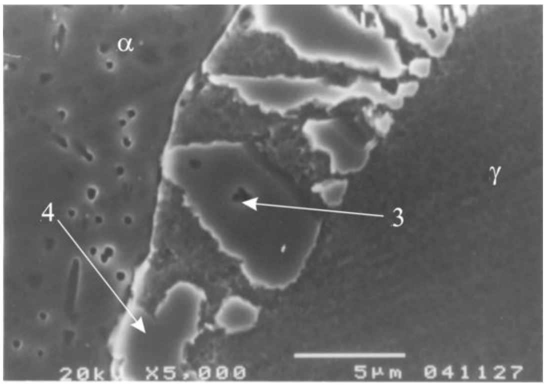

Fig. 3. The ferritic-austenitic microstructure with sigma phase on grain boundaries
Rys. 3. Struktura ferrytyczno-austenityczna z fazą sigma na granicach ziaren

For precise description of the volume fraction of the ferrite, austenite and precipitation network, the quantitative analysis was done using by computer image analyzer Image-Pro Plus. The analysis was done on the microphotographs from the optical microscopy in the magnification 100x. The obtained values was shown in the Figure 4.

The cast steel microstructure contained of about 33% ferrite and 54% austenite. A long time of solidification and cooling after the solidification caused the origination of the precipitation network, consisted mainly of sigma phase, and its volume fraction was estimated of about 13%.

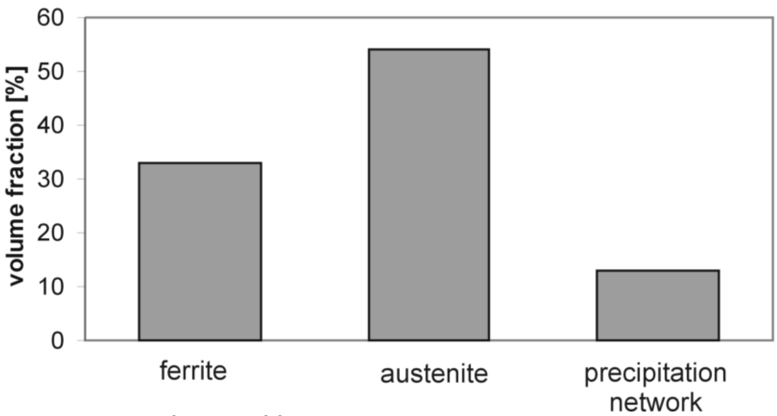

Fig. 4. Volume fraction of ferrite, austenite and precipitation network
Rys. 4. Udział procentowy ferrytu, austenitu oraz siatki wydzieleń

The results obtained from the local microanalysis of the chemical composition (Table 2) showed diversification of the alloying elements concentration in ferrite and austenite. The molybdenum and chromium is the most segregating element (which enriches ferrite), less Ni and Cu (they enrich austenite). The higher content of Mo in the ferrite, especially at the grain boundaries of austenite can be adverse, because this element helps in sigma phase creation. Silicon segregate with the higher difficulty (enriching ferrite).

Table 2. The chemical composition of phases occurred in GX2CrNiMoCu25-6-3-3 cast steel
Tabela 2. Analiza punktowa składu chemicznego staliwa GX2CrNiMoCu25-6-3-3

	Contribution (% wt)					
	Cr	**Ni**	**Cu**	**Mo**	**Fe**	**Si**
ferrite	28,0	4,7	2,0	3,5	61,0	1,1
austenite	22,0	8,8	3,7	1,9	62,8	0,9
precipitation network	32,0	4,4	1,5	5,5	57,5	1,3

Thermo-Calc analysis showed that below 1140^0C the carbides were precipitated in the investigated cast steel (the exemplary chemical composition is given in Table 3). As result of the segregation of the chemical composition they are selectively arranged, mainly near and at the ferrite\austenite grain boundaries (Figure 2). Literature data present some opinion divergences about the carbides influence on the steel properties (especially the corrosion resistance). Some authors declare, that the fine dispersed carbides and probable mechanism of the carbide formation (diffusion of chromium from ferrite) causes no significant menace in the steel properties [4]. There is a widespread opinion, that carbides are the privilege places for other secondary phases nucleation, mainly sigma phase.

Table 3. The chemical composition of phases showed in Fig. 2 and 3
Tabela 3. Analiza punktowa składu chemicznego wydzieleń przedstawionych na rys. 2,3

		Contribution (% wt)				
		Cr	Ni	Mo	Fe	C
Carbides	**1**	33,72	4,25	5,65	41,87	11,01
	2	34,41	5,22	5,25	43,35	9,27
Sigma phase	**3**	42,43	5,89	5,90	43,59	---
	4	36,32	5,82	5,82	49,81	---

The precipitation of the intermetallic sigma phase is observed during the cooling after solidification in the temperature range from about 850°C to 550°C. The chemical composition of this phase is: Fe, 30-50% Cr, 5% Ni, 6% Mo (Table 2).

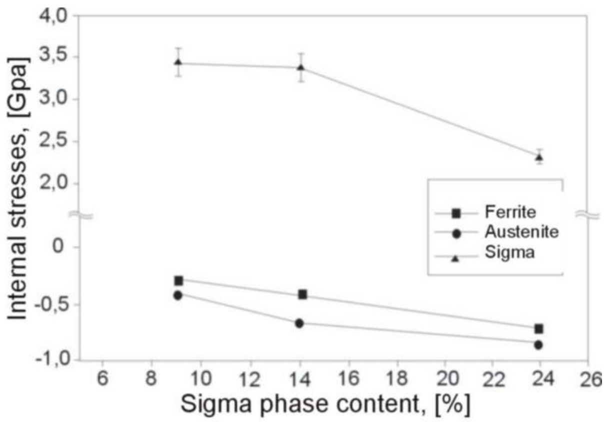

Fig. 4. The influence of sigma phase on the magnitude of internal stresses [2]
Rys. 4. Wpływ ilości fazy sigma na wielkość naprężeń wewnętrznych [2]

The presence of the sigma phase causes the higher brittleness of casts and initiates the micro-cracks formation. It is connected with a very high internal stresses during the formation of this phase. Very hard and brittle sigma phase inclusions are the source of a high concentration of tensile stresses, on the other hand in the ferrite and austenite small compressive stresses can be observed [2]. Cooperation of stresses originated during the solidification and the cooling after the solidification in connection with a high brittleness of the structure caused by presence of sigma phase precipitation, favors the initiation and the propagation of micro-cracks in the cast (according to investigations presented in work [1] the cast steel in as-cast condition has impact resistance KCV<7J).

4. SUMMARY

The obtained results of the investigations prove, that the cracking is initiated and propagated near the grain boundaries, which are the places of privileged precipitation of the hard and brittle sigma phase and carbides. Cracks have intercristalline character, and the size of faces in the fractures correlates with the size of grains formed during the solidification.

These quoted factors, which favor cracks in a duplex casts, show that the higher cooling rate after the solidification process of casting decrease the brittleness, opposite to the conventional carbon or low-alloyed cast steel. To increase the cooling rate, the castings should be removed from a form immediately after their solidification. The construction of casting, and pouring of the metal in the mould cavity should be concerned (the thermal center should be avoided in the casting, a machining allowance should be possibly small because of the economical regards and also because of the casting walls enlargement, which is related with longer time of solidification).

The low temperature of pouring into moulds is also significant. If the higher pouring temperature is given, the higher thermal stresses and lower cooling rate of the casting after solidification is observed. Too high pouring temperature favors the origination of large, long column grains, very adverse for technological and mechanical properties of the casts.

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STRUKTURA KRZEPNIĘCIA MASYWNYCH ODLEWÓW ZE STALIWA TYPU DUPLEX

STRESZCZENIE

W pracy przedstawiono problemy wykonywania masywnych odlewów ze staliwa typu duplex. Przeprowadzono badania makro- i mikrostruktury krzepnięcia staliwa GX2CrNiMoCu25-6-3-3. Opisano wpływ szybkości chłodzenia i segregacji pierwiastków na tworzenie się faz międzymetalicznych, zwłaszcza fazy sigma. Badania wykazały, że proces segregacji pierwiastków stopowych oraz warunki chłodzenia podczas krzepnięcia silnie wpływają na tworzenie się faz międzymetalicznych, a ich wydzielanie w strukturze powoduje pogorszenie własności technologicznych i użytkowych odlewów

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