ARCHIVES
of
FOUNDRY ENGINEERING

ISSN (1897-3310)
Volume 7
Issue 3/2007

269 – 272

48/3

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

Characterization of Solidification and Solid State Transformation in Duplex Cast Steel: Thermo-Calc Investigation

Z. Stradomski [a], D. Dyja [b]*
[a,b] Institute of Materials Engineering; Faculty of Materials Processing Technology and Applied Physics; Czestochowa University of Technology; Al. A. Krajowej 19; 42-200 Czestochowa; Poland
E-mail address: dyjad@mim.pcz.czest.pl

Received on: 18.04.2007; Approved for printing on: 27.04.2007

Abstract

The paper presents a characteristic of solidification process and changes occurring in the solid state in a duplex cast steel. Theoretical chemical composition of individual phases, its changes during solidification and cooling after solidification and also changes in volume fractions of phases versus temperature have been determined. Theoretical results of Thermo-Calc analysis have been correlated with the microstructure of as-cast cast steel as well as with analysis of chemical composition of individual phases, carried out on a scanning microscope equipped with an EDS attachment.

It has been shown that at the carbon content of 0.1% the enrichment of residual liquid phase with carbon results in a peritectic reaction, changing the ferritic solidification model typical for cast steels with low carbon content. In the case of solidification grain boundary areas enrichment with carbon, chromium and molybdenum there is a possibility of carbides precipitation already in the liquid state, what increases propensity for hot cracking and reduces the quality of castings produced. A correlation between theoretical composition of ferrite, austenite and $M_{23}C_6$ carbides, determined based on Thermo-Calc software, and their actual composition determined based on local analyses of chemical composition carried out on a scanning microscope has been shown. The volume fractions of ferrite, austenite and carbides determined using Thermo-Calc software show a strong correlation with actual fractions of those phases in the examined alloy's structure. The chemical composition of ferrite, austenite and carbides determined using Thermo-Calc software does not show any more such strong correlation with the actual chemical composition of those phases determined based on local analyses of chemical composition carried out using a scanning microscope.

Keywords: Metallography, Duplex cast steel, Solidification, Phase Volume fraction, Thermo-Calc analysis

1. Introduction

An increasing customers' demand for castings of components exposed to erosion-corrosion action of media makes that new suggestions appear in the group of materials used for their production, related both to modifications of chemical composition and to optimisation of the structure from the point of view of usable properties [1,2].

High-alloy ferritic-austenitic duplex cast steels are an important and dynamically developing group of erosion and corrosion resistant materials, offering a high resistance to erosion wear combined with high corrosion resistance in a chlorides-containing environment [3,4].

In most grades of duplex cast steels covered by standards the carbon content does not exceed the level of 0.3%, however, reaching it may pose a major technological barrier [5-8]. The grades with much higher carbon content, proposed by the largest world castings manufacturers (Tab. 1), are definitely not an attempt to bypass the problem, but result from their much higher resistance to erosion-corrosion wear. An increased carbon content in duplex cast steels has a favourable influence on erosion resistance, what is related to higher alloy hardness and a possibility of hard carbides and σ phase precipitation in the matrix. This is confirmed by results of studies on corrosion and erosion resistance of GX40CrNiMo27-5 and GX2CrNiMoN22-5-3 ferritic-austenitic cast steels presented in paper [9], where it has been shown that a high-carbon duplex cast steel (HDSC) features higher resistance to erosion and erosion-corrosion wear than a low-carbon cast steel (DS).

Table 1.
The chemical composition of cast steel [9-11]

	C	Cr	Ni	Mo	other
	%	%	%	%	%
standard & superduplex stainless steel (DS)					
KSB-Noridur	**0,04**				
YST130A	**0,05**	27,0	7,0	3,0	---
GX6CrNiMo24-8-2	**0,07**	24,0	8,0	2,2	N-0,15
SCS11	**0,08**	25,0	5,5	2,0	---
GX6CrNiN26-7	**0,08**	26,5	6,5	---	N-0,15
high carbon duplex stainless steel (HCDS)					
GX32CrNiN28-10	**0,30**	27,0	9,0	---	---
GX40CrNiMo27-5	**0,35**	27,0	5,0	2,2	---
GX40CrNi27-4	**0,37**	27,5	4,5	---	---

The studies aimed at presentation of problems related to a change in the solidification mechanism and in transformations proceeding in the solid state in ferritic-austenitic duplex cast steel with carbon content increased to 0.1%.

2. Methodology and materials for research

The chemical composition of the highly-alloy ferritic-austenitic duplex cast steel used for the present work is listed in table 2.

Table 2.
The chemical composition of examined cast steel

C	Cr	Ni	Mo	Cu	Si	S	P
%	%	%	%	%	%	%	%
0,1	24,0	7,6	2,35	2,6	0,94	0,008	0,016

The microscopic investigations were performed on the Zeiss Axiovert 25 optical microscope.

In order to better determined the volume fraction of phases occurring in the cast steel examined, a quantitative phase analysis was performed using the ImagePro Plus analyzer.

The analysis of chemical composition of selected micro-regions was carried out using a JEOL JSM 5400 scanning microscope equipped with an EDS microanalyzer.

Theoretical chemical composition of individual phases, its changes during solidification and cooling after solidification and also changes in volume fractions of phases have been determined on Thermo-Calc for Windows software version 4.0.1.5.

3. Results and discussion

In high-alloy duplex cast steels the increasing of carbon content is accompanied by an increase in segregation processes, what has been confirmed by structural studies on raw cast steel [12,13]. The analysis of the microstructure has shown that it has a two-phase ferritic-austenitic structure with characteristic network of darker etching structure in the boundary areas of solidification grain (Fig. 1).

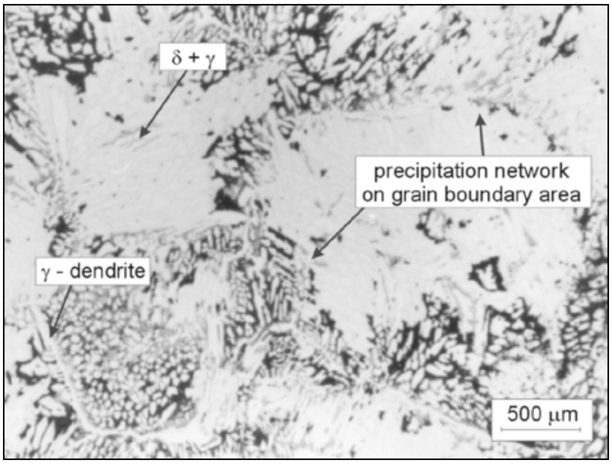

Fig. 1. The microstructure of investigated cast steel in as-cast conditions

The boundary areas of solidification grain are a privileged place for carbides and intermetallic σ phase precipitation during solidification and cooling after solidification, what has been illustrated in Fig. 2. Increased carbon content intensifies the occurring segregation processes and promotes carbides precipitation in the form of carbide eutectic already in the liquid state.

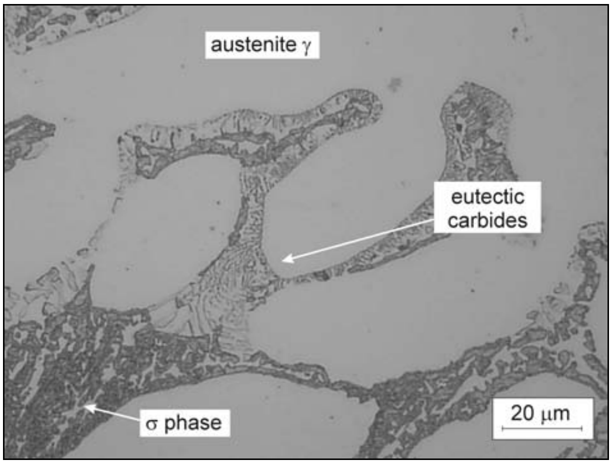

Fig. 2. The boundary area of solidification grain, cast steel in as-cast conditions

It shall be emphasised that the morphology of carbides and σ phase precipitates makes that sometimes they are difficult to distinguish in an optical microscope image, and in addition the σ phase precipitates frequently in the vicinity of or directly on carbides. Diversified structure after solidification and adverse changes occurring during casting's cooling make that micro-areas with precipitated brittle phases, in particular σ phase, promote cracks origination in castings, what has been described at length in authors' paper [14,15].

Results of local analysis of chemical composition of phases occurring in as-cast cast steel, i.e. ferrite, austenite, σ phase and carbides, carried out on a JEOL scanning microscope, have been specified in Table 3. They have shown that the ferrite contains ~28% of Cr and ~5% of Ni, while the austenite ~23% of Cr and ~8.5% of Ni. Carbides precipitating already from the liquid contain ~66%Cr, 1.5%C, and 9%Mo, and the σ phase originating in the solid state – ~42%Cr, and 6%Mo.

Table 3.
Chemical composition of the investigated phases

Phase	Element				
	Cr	Ni	C	Mo	Fe
BCC_A2	27.83	4.83	---	2.72	bal.
FCC_A1	22.87	8.62	---	1.65	bal.
SIGMA	42.43	5.89	---	5.90	bal.
M23C6	66.61	1.48	1.44	9.01	bal.
* *BCC_A2– ferrite, FCC_A1– austenite, SIGMA– σ- phase*					

To determine the volume fraction of ferrite, austenite and carbides in the cast steel, the microstructure was analysed using ImagePro Plus software. The volume fraction of two basic phases, i.e. ferrite and austenite, has been estimated as ~53% and ~45%, respectively, while that of eutectic carbides as ~2%.

To verify the microstructural examinations and analyses of chemical composition of phases carried out, an solidification simulation was performed using Themo-Calc software. Theoretical chemical composition of individual phases and its change during solidification and cooling after solidification for the cast steel analysed has been presented in Table 4, while the change in phases volume fraction versus temperature in Fig. 3. The volume fractions of ferrite (BCC_A2), austenite (FCC_A1) and carbides determined using Thermo-Calc software show a strong correlation with actual fractions of those phases in the examined alloy's structure. Theoretical carbides fraction at ~750°C amounted to 2.17% and their actual fraction in the cast steel containing 0.12%C amounted to ~2.1%.

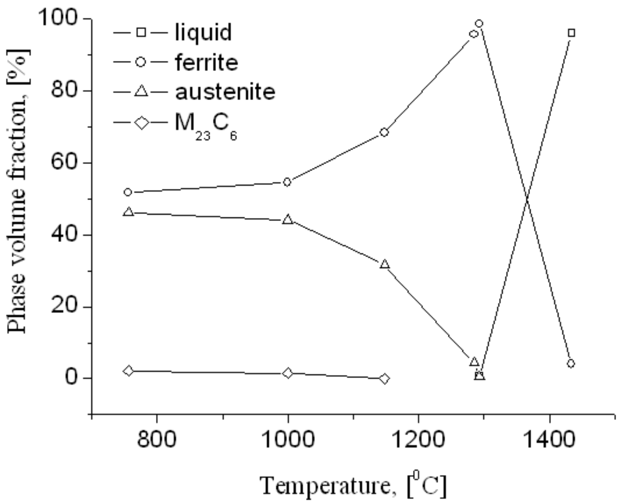

Fig. 3. Change in phases volume fraction versus temperature, Thermo-Calc investigation

The chemical composition of ferrite, austenite and carbides determined using Thermo-Calc software (Table 4) does not show any more such strong correlation with the actual chemical composition of those phases determined based on local analyses of chemical composition carried out using a scanning microscope.

Table 4.
Changes in chemical composition of the investigated phases during solidification and cooling after the solidification measurements by the Thermo-Calc software

Temperature [^{0}C]	Phase	Element							Volume fraction [%]
		Fe	Ni	Si	C	Cr	Mo	Mn	
1434	LIQUID	64,70	7,66	1,01	0,10	23,95	2,3	0,25	95,98
	BCC_A2	65,77	6,14	0,68	0,01	25,01	2,18	0,20	4,016
1293	LIQUID	57,47	9,23	0,86	1,27	27,24	3,59	0,32	0,791
	BCC_A2	64,79	7,56	1,00	0,09	24,00	2,29	0,25	98,68
	FCC_A1	66,34	11,3	0,72	0,24	19,55	1,53	0,26	0,522
1285	BCC_A2	64,67	7,43	1,01	0,09	24,19	2,33	0,25	95,61
	FCC_A1	66,30	11,20	0,73	0,25	19,68	1,56	0,27	4,38
1148	BCC_A2	63,98	6,18	1,10	0,058	25,85	2,57	0,24	68,39
	FCC_A1	66,40	10,66	0,77	0,188	19,99	1,71	0,27	31,59
	M23C6	22,52	0,32	---	5,41	64,65	7,07	0,016	0,006
995	BCC_A2	63,97	5,18	1,19	0,016	26,82	2,57	0,22	54,46
	FCC_A1	67,07	10,77	0,79	0,057	19,33	1,69	0,29	44,07
	M23C6	15,97	0,011	---	5,31	66,66	11,9	0,006	1,46
756	BCC_A2	64,73	3,75	1,35	6E-06	27,78	2,20	0,18	51,63
	FCC_A1	67,09	12,15	0,66	0,002	18,01	1,74	0,34	46,16
	M23C6	8,0	0,013	---	5,17	68,42	18,39	---	2,17
	SIGMA	44,01	5,89	---	---	41,86	8,18	0,036	0,034

4. Conclusions

The examinations carried out allow formulating the following statements and conclusions:

- at the carbon content of 0.1% the enrichment of residual liquid phase with carbon results in a peritectic reaction, changing the ferritic solidification model typical for cast steels with low carbon content;
- in the case of solidification grain boundary areas enrichment with carbon, chromium and molybdenum there is a possibility of carbides precipitation already in the liquid state, what increases propensity for hot cracking and reduces the quality of castings produced
- volume fractions of ferrite, austenite and carbides determined using Thermo-Calc software show a strong correlation with actual fractions of those phases in the examined alloy's structure. The chemical composition of ferrite, austenite and carbides determined using Thermo-Calc software does not show any more such strong correlation with the actual chemical composition of those phases determined based on local analyses of chemical composition carried out using a scanning microscope

Acknowledgements

The financial support by the Polish State Committee for Scientific Research No N507 086 31/2065 is gratefully acknowledged

References

[1] P. Li, Q. Cai, B. Wei, Failure analysis of the impeller of slurry pump used in zinc hydrometallurgy process, Engineering Failure Analysis, 13 (2006), 876–885.
[2] D. Dyja, Z. Stradomski, S. Stachura, Possibilities of microstructure steering in ferritic-austenitic cast steel type GX2CrNiMoCu25-6-3-3, Archives of Foundry, Vol. 6, No. 18 (2006) 459-464 (in Polish).
[3] H. Berns, A. Kühl, Reduction in wear of sewage pump through solution nitriding, Wear, 256 (2004), 16–20.
[4] G. Lothongkum, P. Wongpanya, S. Morito, T. Furuhara, T. Maki, Effect of nitrogen on corrosion behavior of 28Cr–7Ni duplex and microduplex stainless steels in air-saturated 3.5wt% NaCl solution, Corrosion Science, 48 (2006), 137–153.
[5] J.-C. Tissier, D. Balloy, J. Dairon, S. Dorlencourt, J.-J. Ninin, Vacuum decarburization: a solution within reach of small foundries, Fonderie Fondeur d'Aujourd'hui, No. 246 (2005) 28-39.
[6] J. Dairon, S. Dorlencourt, J.-C. Tissier, D. Balloy, J.-J. Ninin, Vacuum decarburization: a solution within reach of small foundries, Fonderie Fondeur d'Aujourd'hui, No. 249 (2005), 26-39.
[7] Z. Stradomski, S. Stachura, D. Dyja, Ferritic-austenitic cast steel – perspective and problems, Hutnik - Wiadomości hutnicze, No. 6 (2006), 275-279 (in Polish).
[8] J. Głownia, Obróbka pozapiecowa staliwa uszlachetnia tworzywo na odlewy pracujące w trudnych warunkach, Przegląd Odlewnictwa, No. 9 (2000), 340-344 (in Polish).
[9] W. Hubner, E. Leitel, Peculiarities of erosion-corrosion processes, Tribology International, Vol. 29 (1996), 199-206.
[10] Cast materials from KSB, www. ksbgroup.com/ksb /web /COM/en/COM__en__Root.html
[11] www.kuhn-edelstahl.com/englisch/index.php?tab=110
[12] D. Dyja, Z. Stradomski, S. Stachura, Solidification structure of massive castings from duplex cast steel, Archives of Foundry, Vol. 5 (2005), 79-86.
[13] D. Dyja, Z. Stradomski, Solidification model of high alloy Fe-Cr-Ni cast steels, Archives of Foundry, Vol. 6, No 19 (2006), 81-88, (in Polish).
[14] Z. Stradomski, S. Stachura, D. Dyja, A. Zyska, Technological problems in elaboration of massive castings from duplex cast steel in aspect of production process optimization, Archives of Foundry, Vol. 5, No. 17 (2005), (in Polish).
[15] Z. Stradomski, S. Stachura, D. Dyja, Technological problems in elaboration of massive casting from duplex cast steel, SSW 2005 Conference&Expo, Maastricht, Netherlands (2005), 363-368.