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Prediction of Ferrite Content in Austenitic Cr-Ni Steel Castings During Production

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Abstract

Determination of the ferrite content in austenitic steels, which solidified under defined conditions. Ferrite content in austenitic matrix was determined from samples with wall thickness of 60 mm. Measured ferrite contents served to propose the regression equations for the calculation of the ferrite content in steels with Cr content of 18 up to 22 % and Ni of 9 up to 11 %. An additional regression equation was proposed for steels with a higher Ni content. The proposed regression equations have been checked up on the operating melts. In conclusion, the ferrite content in the axis of the casting of wall thickness of 500 mm has been calculated and it was compared to the ferrite determined in the usual way from the cast-on test.

Keywords: Solidification, Metallography, Austenitic steel, Austenite, Ferrite, DeLong diagram

1. Introduction

In austenitic steels a certain amount of ferrite may be present [1, 2]. The European standard EN 10283 lists besides the austenitic steels the fully austenitic steels too, in which the ferrite content is not permitted. Ferrite content in austenitic steels is permitted, but usually it is limited by technical delivery terms for individual castings. The ferrite content in steel depends in particular on chemical composition, but also on the solidification conditions. Schaeffler published already in 1949 the diagram for determination of the ferrite content in chromium-nickel steels based on the nickel-equivalent and the chrome-equivalent [3]. The Schaeffler diagram for austenitic steels with a low ferrite content was specified by DeLong [4]. The DeLong diagram provides the influence of nickel-equivalent and the chrome-equivalent on the ferrite content in the austenitic matrix up to 13.8 % of ferrite. Both of the cited works were devoted to the structure of the weld metal.

The presented work also deals with comparing the ferrite content in the austenitic matrix of heavy castings with the results of the given DeLong work and statistical processing of the ferrite content in austenitic steels, which solidified under defined conditions.

2. The objective of the work

Based on the experimental melts to describe the influence of the nickel- and chrome-equivalent in the cast steel on the ferrite content in the austenitic matrix in steels with nickel content of 9 up to 11 % and chromium content of 18 up to 22 %.

3. Design and implementation of the experiment

Based on a statistical model the 31 melts were made. Samples with a wall thickness of 60 mm were cast from the melts. For solving the ferrite content there are more methods that have their advantages and disadvantages.

Based on the Table 1 the full austenitic steels without ferrite content can be evaluated with the aid of Ni_{eq}/Cr_{eq} and namely in the case that the ratio of $Ni_{eq}/Cr_{eq} \geq 0.75$. With lower Ni_{eq}/Cr_{eq} values the ferrite was already present in the austenitic structure. According to Table 1 with the Ni_{eq}/Cr_{eq} ratio of 0.55 up to 0.76 the ferrite occurred in structure in the amount of 0.8 up to 9.5 %. For two-phase steels containing 19.9 up to 48.8 % of ferrite the Ni_{eq}/Cr_{eq} value ranged in an interval of 0.45 to 0.58.

Ferrite in this work was measured planimetrically on metallographic samples using the LUCIE II program on the Opemus microscope. Ferrite content for each melt was measured twice. The method was chosen because in cooperating plant it is used to declare the ferrite content in metallurgical certificates. Samples for measuring the ferrite content were taken every time from the same place of the casting. The nickel-equivalent and the chrome-equivalent were calculated from the chemical composition. Based on the chemical composition the regression equation for the dependency of the ferrite content in the austenitic matrix on the chemical composition was determined.

From the DeLong diagram the ferrite content in the austenitic matrix was read too and the graphically expressed dependency was described by a simple regression equation :

$$ferrite\,\% = 13.37 + 1.45 \cdot Cr_{eq} - 55.21 \cdot \left(\frac{Ni_{eq}}{Cr_{eq}}\right) \quad (1)$$

The standard deviation of the regression equation is s = 0.43% of ferrite.

More samples for determination of ferrite content in the austenitic matrix were cast from operating melts weighing 15 t and they were used for the verification of the proposed prediction of the ferrite content. At the end of the work a casting of wall thickness of 500 mm was cast and in the casting axis the ferrite contents were also determined and compared to values calculated on the basis of the regression equation set below.

4. Interpretation of values measured from pilot plant and operational melts

Ferrite content in studied experimental melts correlates to the ratio (Ni equivalent/Cr equivalent). Results are given in **Table 1**.

For austenitic steels with ferrite content up to 9.5 % in pilot plant and operational melts the equation (2) has been obtained from the measured data using the regression analysis.

$$ferrite\,\% = \exp\left\{2.66 + 0.225 \cdot Cr - 9 \cdot \left(\frac{Ni_{eq}}{Cr_{eq}}\right)\right\} \quad (2)$$

Basic characteristics of the file of measured values and the file of calculated values according to the equation (2) and their comparison is shown in Table 2. These are files of austenitic steels with ferrite content from 0.8 up to 9.5 %.

Deviations of the measured and calculated values range in the interval of – 1.36 up to + 1.84 %.

Based on the equation (2) the ferrite content in two operational melts with a higher ferrite content was evaluated. The measurement and calculation results are given in Table 3.

Chemical composition of the grade A351CF3M (16.54 %) does not meet the conditions for the equation (2). The calculated value of the ferrite content differs from the measured one only about half a percent. In the case of A351CE8MN steel the calculated value is lower by 3.45 %.

Table 1.
Tolerance for the ferrite content in dependence on the Ni_{eq}/Cr_{eq} ratio

Ferrite	Ferrite	Ferrite	Ferrite
0 up to 0.8 %	0.8 up to 4.5 %	4.5 up to 9.5 %	19.9 up to 48.8 %
Ni_{eq}/Cr_{eq}	Ni_{eq}/Cr_{eq}	Ni_{eq}/Cr_{eq}	Ni_{eq}/Cr_{eq}
0.75 up to 1.69	0.55 up to 0.76	0.54 up to 0.60	0.45 up to 0.58

Cr_{eq} = %Cr+%Mo+1,5%Si, Ni_{eq} = %Ni+0,5%Mn + 30(C+N)

Table 2.
Measured and calculated ferrite contents and their comparison

ferrite = 0.8 up to 9.5 %					
ln ferrite = 2.66 + 0.225 Cr – 9 Ni_{eq}/Cr_{eq}					
measured				calculated	
n = 14	ferrite	Ni_{eq}	Cr_{eq}	ferrite	deviation
[-]	[%]	[%]	[%]	[%]	[%]
average	4.06	12.91	20.63	3.94	0.12
s	2.441	1.835	0.876	2.211	0.981
min	0.53	11.20	19.20	0.88	-1.36
max	9.47	16.60	22.50	8.34	1.84

Table 3.
Measured and calculated ferrite contents in operational melts and their comparison

	Measured							calculated	
standard	C	S	Cr	Ni	Mo	N	Ni_{eq}/Cr_{eq}	ferrite	deviation
	[%]	[%]	[%]	[%]	[%]	[%]	-	[%]	[%]
A351CF3M	0.03	0.005	20.5	9.7	2.75	0.125	0.61	16.54	- 0.54
A351CE8MN	0.066	0.004	22.9	9.75	3.25	0.1645	0.61	22.55	3.45

5. Comparison of ferrite contents measured in the austenitic matrix with data read from the DeLong diagram

According to the equation (1) the ferrite content was calculated, which may be read from the DeLong diagram, and it was compared with the actually measured values of ferrite in austenitic steels containing ferrite up to approx. 10 %. Basic statistical characteristics of the data file calculated from equation (1) and the data actually measured on experimental castings are given in Table 4 and graphically in Figure 1.

It follows from the Table 4 that ferrite values measured in austenitic matrix of heavy castings are lower than the values from the diagram, and namely in average by 4.76%. The largest deviation of the measured values from the values calculated according to the equation (1) is – 9.64 %.

The correlation is statistically significant in the significance level of p = 0.05, but as mentioned above, from a technical standpoint, there is a significant difference between actually measured values of ferrite content in the austenitic matrix and the values read from the DeLong diagram.

6. Calculation of the ferrite content in the austenitic matrix with concentration higher than 13.8 %

For melts with a higher ferrite content a regression equation (3) was calculated. For the calculation of the equation a file of all melts with ferrite content higher than 13.8 % was used including the operational melts produced in a 15 t electric arc furnace using the electric arc furnace + LF + VOD process.

$$ferrite\,\% = exp\left\{7.223 + 4.37 \cdot C + 5.74 \cdot N - 8.67 \cdot \left(\frac{Ni_{eq}}{Cr_{eq}}\right)\right\} \quad (3)$$

The equation can be used up to approximately 25 % of ferrite in austenitic structure. Castings, from which the samples were taken to determine the ferrite content, cooled under the same conditions as previously mentioned samples.

7. Checking the regression equation (3) for the calculation of ferrite content in the casting with 500 mm wall thickness

From the point of view of chemical composition the heavy castings are not homogeneous. The ferrite content in different places of the casting is different too. From this point of view the calculations according to the equation mentioned above may be informational only.

From the A351CF3M grade referred to in Table 3 a casting in a cube form was cast. From the central part of the casting a plate was cut, which contained the axis of the casting from the heel to the riser. After treating the plate the samples were taken from the casting axis in the points approximately 70 mm apart, these samples were chemically analysed and ferrite content was determined. Based on the measured chemical composition the ferrite content in the studied points of the casting was calculated according to the equation (3). Chemical composition of the steel in mentioned places and the measured and calculated ferrite content are given in Table 5. Ferrite contents ranged in an interval of 16.06 up to 19.54 % with an average value of 18.06 %. The results of the measured and calculated values are listed in Table 5. Table 5 also shows the nickel and chromium equivalents used for the calculation according the equation (3).

Ferrite content in the melting wedge was determined to 16.54 %. The average value of ferrite content calculated for points in thermal axis differs from the average value 3.00 % found in the cast-on wedge.

Table 4.
Measured and calculated ferrite contents and comparison of them

ferrite = 0.8 up to 9.5 %					
	Measured values			Calculated values	
n = 36	ferrite	Ni_{eq}	Cr_{eq}	ferrite	deviation
[-]	[%]	[%]	[%]	[%]	[%]
average	4.32	12.82	20.72	9.18	-4.76
s	2.422	1.671	0.874	3.859	2.547
min	0.2	11.19	19.20	1.13	-9.63
max	9.47	16.60	22.50	14.93	-0.22

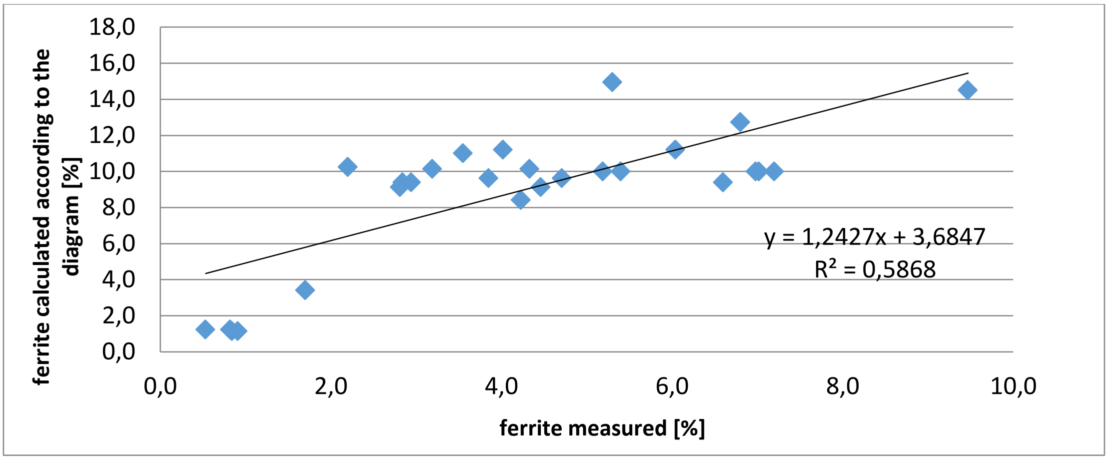

Fig. 1. The correlation between the measured ferrite content and ferrite content values calculated according to the equation (1)

Table 5.
Calculation of the ferrite content based on the equation (3) in the axis of the casting of a cube 500 x 500 x 500 mm

Sample	C	N	Ni_{eq}	Cr_{eq}	Ni_{eq}/Cr_{eq}	calculation
No	[%]	[%]	[%]	[%]	-	[%]
A22	0.030	0.125	14.6	24.324	0.600	17.60
B22	0.030	0.150	14.68	23.896	0.614	18.03
C22	0.028	0.145	14.66	23.548	0.623	16.06
D22	0.028	0.151	14.47	23.896	0.606	19.20
E22	0.027	0.145	14.49	23.928	0.606	18.53
F22	0.027	0.147	14.62	23.784	0.615	17.34
G22	0.026	0.155	14.57	24.048	0.606	19.54
H22	0.028	0.152	14.67	23.909	0.614	18.08
average	0.028	0.1462	14.59	23.91	0.610	18.06
s	0.0014	0.0092	0.0801	0.2196	0.0072	1.1070
min	0.026	0.125	14.470	23.548	0.600	16.06
max	0.030	0.155	14.680	24.324	0.623	19.54

8. Summary

The measured values of the ferrite content in wedges with a wall thickness of 60 mm were compared with the DeLong diagram. The measured values of the ferrite content in the austenitic matrix in some cases deviated significantly from the DeLong diagram. For steels with ferrite content of up to approx. 10 % the equation (2) was calculated based on the pilot plant and operational melts, which with technically sufficient precision enables to calculate the ferrite content in the austenitic matrix based on the chemical composition of the steel.

For steels with ferrite content of up to approx. 20 % the equation (3) was calculated. The values of ferrite content calculated from the chemical composition were verified on 8 samples taken from the casting axis of dimensions 500 x 500 x 500 mm. The deviation of calculated and measured values is also technically applicable.

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