Contributions related to the control of steel ingot solidification

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Abstract. The paper introduces the influence of the control over steel ingot solidification upon the quality characteristics of carbon steels. The laboratory experiments focused on the solidification control of steel ingots with cylindrical cross-section, by addition of crystallizing germs (micro-coolers) in their central area, in order to influence their inner structure and quality characteristics. The use of graphical and analytical correlations allows the establishing of optimal technological domains of variation for the steel casting parameters, with use of micro-coolers, in order to obtain the desired values for their mechanical characteristics.

1. Introduction

The basic problems that must be resolved casting steel it consist in obtain of homogeneous ingots from chemical point of view structural and mechanic properties. To mitigate the deficiency of ingots solidification in case of classical cast is necessary to adapt an efficient method to evacuate the heat from the steel in course of solidification. Usually the rapid heat evacuate is ensured through the creation of suddenly gradient of temperature in parts that solidification, as in liquid phase of the ingot. In this case, excepting the over heating must be field in most part and physic heat of cooling of the steel overlay that had been solidificated [1]. Conducting the crystalline structure can be realized using the temperature gradient (considerate basic parameter) from the liquid phase adjoining with the solidificated ingots font.

To conduct the solidification it can be utilized three methods, namely [2]:

- Using an alternative or continuous magnetic field for stopping the contraction of the currents from the liquid steel from the middle of the block of changing the movement direction
- Using the micro-coolers under forms of powder or granules metallic who reduce the gradient of temperature and influence the circulation of steel not solidified
- Enlarging the speed of solidification steel.

The micro-coolers used leads to reduce the piping extent, of the segregation, to improve the solidification structure and for values for physic-mechanic characteristic.

The method of ingot casting with micro-coolers is particularly recommended for the casting of large steel ingots, which are most likely to develop flaws such as: segregations, micro-shrinkages axial porosities and hot cracks. The process of steel crystallizing with exogenous germs introduced by means of micro-coolers differs considerably from the one used in common cast steel.

The micro-coolers introduced into the liquid alloy during casting, take over the overheating and also part of the solidification heat, some of them remaining into the liquid alloy as crystallizing germs. In order to obtain the desired effect, the micro-coolers have to be evenly distributed into the mass of
liquid steel so that the action and sub-cooling areas created by each micro-cooler should partially overlap or be tangent.

The micro-coolers used to control the solidification process have to meet the following conditions [3]: to have high purity in terms of oxide inclusions, humidity should not exceed 0.25%, and not to have a stained surface; their chemical composition should be similar to that of the steel to be cast, and the grain size should be as even as possible.

2. Experimental researches

The steel was elaborated in the laboratory in a 10 kg induction furnace and the steel was cast into 2.5 kg circular cross-section ingots. The micro-coolers used were obtained by cutting pieces of steel wire with a diameter of 1mm. The micro-cooler addition was 1-4 g/kg of cast steel. The micro-coolers were introduced into the mold when the latter was filled by 30%, 60% and 90% and in equal quantities (figure 1). These filling levels were established taking into consideration the local researches and the reference literature [4-7]. After having filled the mold, the end of the ingot was spread with anti-shrinkage dust. The resulting semi-finished parts were sampled in order to determine their physical and chemical characteristics.

The experimental data have been modeled by 1st, 2nd, 3rd and 4th degree polynomial surfaces. This polynomial modeling was done in Matlab. The coefficients of the regression surface for each degree of the polynomial surface were obtained by the method of the smallest squares.

The data resulting from the experiments are considered to be the values of independent variables \( d \) (diameter micro-coolers) and \( q \) (specific consumption of micro-coolers), and the values of dependent variable \( A \) (elongation) are compared to the values obtained by mathematical modeling, which gives the values of the deviations from the regression surface for each degree of the surface under analysis.

The equations describing the regression surfaces - 1st degree \((A)\), the correlation coefficients and the deviation from the regression surface corresponding to this modeling are:

\[
A = 1.10 \ d + 0.20 \ q + 21.97
\]

Correlation coefficient: \( R = 0.36 \). Deviation from the regression surface: \( S = 0.65 \).

Point of maximum: \( d = 1 \text{ mm}; q = 4.0 \text{ g/kg}; A = 23.88\% \).
The modeling resulted in the 1st degree polynomial surfaces shown in figure 2. The equations describing the regression surfaces – 2nd degree (A), the correlation coefficients and the deviation from the regression surface corresponding to this modeling are:

\[ A = -13.93 \cdot d^2 - 0.09 \cdot d \cdot q - 0.61 \cdot q^2 + 23.63 \cdot d + 3.32 \cdot q + 9.9452 \]  

(2)

Correlation coefficient: \( R = 0.89 \). Deviation from the regression surface: \( S = 0.30 \). Point of maximum: \( d = 0.84 \text{mm}; q = 2.65 \text{g/kg}; A = 24.28\% \).

The modeling resulted in the 2nd degree polynomial surfaces shown in figure 3.
The equations describing the regression surfaces – 3rd degree (A), the correlation coefficients and the deviation from the regression surface corresponding to this modeling are:

\[ A = -23.36 d^3 + 0.76 d^2 q + 0.25 d q^2 + 0.085 q^3 + 40.23 d^2 + 2.60 d q - 1.4563 q^2 - 16.0275 d + 6.2837 q + 18.0443 \]  

(3)

Correlation coefficient: \( R = 0.90 \). Deviation from the regression surface: \( S = 0.26 \). Point of maximum: \( d = 0.86 \text{mm}; q = 2.51 \text{g/kg}; A = 24.29\% \).

The modeling resulted in the 3rd degree polynomial surfaces shown in figure 4.

Figure 4. \( A=f(q,d) \) - the 1st degree polynomial surfaces

Figure 5. \( A=f(q,d) \) - the 2nd degree polynomial surfaces
The equations describing the regression surfaces – 4th degree (A), the correlation coefficients and the deviation from the regression surface corresponding to this modeling are:

\[
A = 322.85 \, d^4 + 3.73 \, d^3 \, q + 2.67 \, d^2 \, q^2 - 0.06 \, d \, q^3 + 0.42 \, q^4 - 1065.85 \, d^4 \, q - 3.57 \, d^2 \, q^2 - 4.10 \, q^3 + 1065.85 \, d^4 \, q - 21.60 \, d^2 \, q - 3.57 \, d \, q^2 - 4.10 \, q^3 + 1302.20 \, d^2 + 24.84 \, d \, q + 14.73 \, q^2 - 693.81 \, d - 24.44 \, q + 164.40
\]  

\[R = 0.95, \quad S = 0.19, \quad \text{Point of maximum: } d = 0.82\, \text{mm}; q = 2.50\, \text{g/kg}; A = 24.66\%.
\]

The modeling resulted in the 4th degree polynomial surfaces shown in figure 5.

3. Conclusions

From the analysis of correlations obtained by experimental data in Matlab program, and expressed in analytical and graphical form, results the following conclusions:

- were obtained equations of double correlation expressed by the polynomial function of degree 1 and 2, dependent parameters are the mechanical characteristics (A) and independent parameters of micro cooler diameter (d) and specific addition (q);
- the functions of second degree, provide great dependencies tracked;
- correlations allow establishing the optimal variation for diameter of the micro cooler and specific addition of them;
- graphics allow a relatively simple determination for a given value of the dependent parameter values for the independent parameters (the diameter of micro cooler and specific addition of them).

References

[1] Eftimov V A 1976 Steel casting and crystallization (Bucureşti: Tehnica) p 209
[2] Bratu C and Sofroni L 1981 Conducting research on the crystallization process of steels using micro-coolers Metalurgia 6 220
[3] Ioan R 2000 Theoretical and experimental research in steel solidification (Deva: Destin) p 70
[4] Andronache C, Socalici A, Hepuţ T and Popa E 2012 Research on the influence of ingot solidification process control on the tenacity characteristics Met. Int. 9 243
[5] Andronache C, Socalici A and Hepuţ T 2013 The influence of micro-coolers on the physical-mechanical characteristics of the steel used in making railway monoblock wheels Technical Gazette 3 419