The influence of cooling parameters on the speed of continuous steel casting

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Abstract. This paper analyzes the cooling parameters of the continuous casting speed. In the researches carried out we aimed to establish some correlation equations between the parameters characterizing the continuous casting process, the temperature of the steel at the entrance to the crystallizer, the superheating of the steel and the flow of the cooling water in the crystallizer and different zones of the secondary cooling. Parallel to these parameters were also the values for the casting speed. The research was made for the casting of round Φ270mm semi-finished steel products. The steel was developed in an electric EBT furnace with a capacity of 100t, treated in L.F. (Ladle - Furnace) and VD (Vacuum-Degassing) and poured in a 5-wire continuous casting plant. The obtained data was processed in MATLAB using three types of correlation equations. The obtained results are presented both in the analytical and graphical form, each correlation being analyzed from the technological point of view, indicating the optimal values for the independent parameters monitored. In the analysis we present a comparison between the results obtained after the three types of equations for each correlation.

1. Introduction
A very important component of the continuous casting installation is the secondary cooling zone. The secondary cooling zone has the role to continue the wire cooling after it has emerged from the crystallizing and to assure the total solidification of the semi-product. It is considered “the heart” of a continuous casting and has the role of ensuring the quality of the material, the material surface shape and to ensure a homogeneous cooling and a uniform repartition of the water on the materials surface [1-3].

In most cases the crust doesn’t offer sufficient mechanical resistance to the action of ferro static pressure. To complete solidification and guidance in good conditions of the wire it is created the secondary cooling zone. This cooling is achieved by direct spraying pressurized water, through nozzles, it is able to cross the steam layer formed by evaporation and ensure continuous water-metal contact [4-7].

The secondary cooling can be made in different cooling environments. In practice, the water is used especially as cooling agent that is sprayed through nozzles (circular conical, conical ring and
slot). In special cases it is added to the water compressed air for optimizing the automation sprayed water [7-10].

2. Data processing

Data obtained was processed in MATLAB using three types of correlation equations (z - dependent parameter; x, y - independent parameters):

\[
\begin{align*}
    z &= a_1 x^2 + a_2 y^2 + a_3 xy + a_4 x + a_5 y + a_6 \\
    z &= a_1 + a_2 x + a_3 x^2 + a_4 y + a_5 y^2 + a_6 xy + a_7 x^3 + a_8 y^3 + a_9 + a_{10} y^4 \\
    z &= a_1 + a_2 \log(x) + a_3 \log(x)^2 + a_4 \log(x)^3 + \frac{a_5}{y} + \frac{a_6}{y^2} + \frac{a_7}{y^3} + \frac{a_8}{y^4} + \frac{a_9}{y^5} 
\end{align*}
\]

- \( z \) - casting speed, m / min
- \( x \) - steel temperature at casting [°C], for all correlations;
- \( y \) - cooling water flow in zone 1 [l / min], for the correlations in Figures 1, 2 and 3;
- \( y \) - cooling water flow in zone 2 [l / min], for the correlations in Figures 4, 5 and 6;
- \( y \) - cooling water flow in zone 3 [l / min], for the correlations in Figures 7, 8 and 9.

The obtained results are presented in graphic form, as follows: a) the correlation surface; b) in the projection plane contour; c) the spatial contour projection.

In a first analysis, it can be observed that equation 1 has the simplest analytical form (polynomial of degree 2) compared to polynomial level 5 (equation 2) and especially with equation 3 (logarithmic - polynomial combination).

3. Results

\[ \begin{align*}
    a_1 &= 0.00065; \quad a_2 = 0.00258; \\
    a_3 &= 0.00925; \quad a_4 = -2.47158; \\
    a_5 &= -14.56371; \quad a_6 = 2274.28489;
\end{align*} \]

\[ \frac{R^2}{R^2} = 0.71748; \]

**Figure 1.** Casting speed= f (Steel temperature at casting, Water flow in area 1, equation 1);

a) correlation surface; b) outline in plain; c) contour in space;

**Equation 1:**

\[ z = a_1 x^2 + a_2 y^2 + a_3 xy + a_4 x + a_5 y + a_6 \]
Figure 2. Casting speed = f (Steel temperature at casting, Water flow in area 1, equation 2); a) correlation surface; b) outline in plain; c) contour in space;

Equation 2:
\[ z = a_1 + a_2x + a_3x^2 + a_4y + a_5y^2 + a_6y^3 + a_7y^4 + a_8y^5 \]
\[ R^2 = 0.79421; \]
\[ a_1 = 0; \quad a_2 = -1.59968; \]
\[ a_3 = 0.00092; \quad a_4 = 0; \]
\[ a_5 = 0; \quad a_6 = 3.71578; \]
\[ a_7 = -0.14897; \quad a_8 = 0.00223; \]
\[ a_9 = 0; \]

Figure 3. Casting speed = f (Steel temperature at casting, Water flow in area 1, equation 3); a) correlation surface; b) outline in plain; c) contour in space;

Equation 3:
\[ z = a_1 + a_2\log(x) + a_3\log(x)^2 + a_4\log(x)^3 + \left( a_5 + a_6\frac{y}{y^2} + a_7\frac{y^2}{y^3} + a_8\frac{y^3}{y^4} + a_9\frac{y^4}{y^5} \right) \]
\[ R^2 = 0.702100744917242; \]
\[ a_1 = 21424; \quad a_2 = -87475; \]
\[ a_3 = 11905; \quad a_4 = -54000; \]
\[ a_5 = 44161; \quad a_6 = -22154; \]
\[ a_7 = 0; \quad a_8 = 0; \quad a_9 = 0; \]
Figure 4. Casting speed = f (Steel temperature at casting, Water flow in area 2, equation 1);
a) correlation surface; b) outline in plain; c) contour in space;

**Equation 1:**
\[ z = a_1 x^2 + a_2 y^2 + a_3 x y + a_4 x + a_5 y + a_6 \]
\[ R^2 = 0.76230; \]
\[ a_1 = -0.00023; a_2 = -0.02534; \]
\[ a_3 = -0.00013; a_4 = 0.73284; \]
\[ a_5 = 2.79633; a_6 = -627.26823; \]

Figure 5. Casting speed = f (Steel temperature at casting, Water flow in area 2, equation 2);
a) correlation surface; b) outline in plain; c) contour in space;

**Equation 2:**
\[ z = a_1 x + a_2 x^3 + a_3 x^2 + a_4 y^3 + a_5 y^2 + a_6 x y + a_7 y + a_8 y^5 \]
\[ R^2 = 0.86142; \]
\[ a_1 = -70.41481; \]
\[ a_2 = 2.72890; a_3 = -0.03963; \]
\[ a_4 = -0.03963; \]
\[ a_5 = -0.02389; a_6 = 0; \]
\[ a_7 = -70.41481; \]
\[ a_8 = 2.72890; \]
Figure 6. Casting speed = f(Steel temperature at casting, Water flow in area 2, equation 3);

a) correlation surface; b) outline in plain; c) contour in space;

**Equation 3:**

\[
z = a_1 + a_2 \log(x) + a_3 \log(x)^2 + a_4 \log(x)^3 + \\
+ a_5 + a_6 + a_7 + a_8 + a_9 + a_10
\]

\[
R^2 = 0.79973; \quad a_1 = -78060; \quad a_2 = 31882;
\]

\[
a_3 = -43407; \quad a_4 = 197000;
\]

\[
a_5 = 17588; \quad a_6 = -88439;
\]

\[
a_7 = 14811; \quad a_8 = 0; \quad a_9 = 0;
\]
Figure 7. Casting speed $= f$ (Steel temperature at casting, Water flow in area 3, equation 1); a) correlation surface; b) outline in plain; c) contour in space;

**Equation 1:**

$$z = a_1 x^2 + a_2 y^2 + a_3 xy + a_4 x + a_5 y + a_6$$

$R^2 = 0.68311$;

$a_1 = 0.00063$; $a_2 = -0.00037$;

$a_3 = 0.00755$; $a_4 = -2.37357$;

$a_5 = -11.63264$; $a_6 = 2150.49806$;

Figure 8. Casting speed $= f$ (Steel temperature at casting, Water flow in area 3, equation 2); a) correlation surface; b) outline in plain; c) contour in space;

**Equation 2:**

$$z = a_1 + a_2 x + a_3 x^2 + a_4 y + a_5 y^2 + a_6 y^3 + a_7 y^4 + a_8 y^5$$

$R^2 = 0.62121$;

$a_1 = 0$; $a_2 = -8.35244$;

$a_3 = 0.00543$; $a_4 = 0$;

$a_5 = 0$; $a_6 = 13.73756$;

$a_7 = -0.49166$; $a_8 = 0.00659$;

$a_9 = 0$;
4. Technological analysis of the obtained results

Following the processing of the data collected in the industrial experiments and their processing in MATLAB, three groups of double correlations were obtained using 3 types of correlation equations. All the correlations obtained are presented in analytical and graphic form, being representative in a technological sense.

Regarding the casting temperature, the graphical representations confirm that an increase in the casting temperature results in a reduction of the casting speed, which ensures an optimal heat removal from the liquid - crystalliser steel system, in the cooling water crystalliser system, respectively secondary cooling area.

In all three correlation groups, respectively, the three types in each group, the influence of temperature has the same meaning. For example, Figures 3, 4 and 5 show that:

- Figure 3 at a steel temperature of 150 °C and the secondary cooling rate in zone 2 of 51 l/min., the casting speed is 1.9 m/min, and in Figure 5 all at 1.9 m/min;
- Figure 6 at the same values for the aforesaid parameters, the casting speed is also 1.95 m/min, a difference of 2.62% compared to the two previously presented cases, therefore in unstable practice conditions;

It should be mentioned that in the case of the other correlation groups, respectively the three types of equations used in each group, similarly correlated results are obtained

5. Conclusions

On the basis of the researches conducted, respectively on the obtained results can be concluded the following:

- between the cooling parameter in the secondary area of the continuous casting installation and the continuous casting speed of the steel can be established representative technology correlations, analytically expressed and graphically;
- on the basis of the graphical representations, depending on the steel casting temperature and the flow rate of the casting water, the casting speed can be chosen;
- the results can be used in the casting of semi-finished products Ø 180 mm.

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