

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

G O Tirian<sup>1</sup>, C A Gheorghiu<sup>2</sup>, T Hepuș<sup>2</sup> and C P Chioncel<sup>3</sup>

<sup>1</sup>Politehnica University of Timisoara, Electrotechnical Engineering and Industrial Informatics Department, 5 Revolution Street, Hunedoara, 331128, Romania

<sup>2</sup>Politehnica University of Timisoara, Department of Engineering and Management, 5 Revolution Street, Hunedoara, 331128, Romania

<sup>3</sup>Eftimie Murgu University/Electrical Engineering and Informatics, Resita, Romania

E-mail: [ovidiu.tirian@fih.upt.ro](mailto:ovidiu.tirian@fih.upt.ro)

**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  $\phi 270\text{mm}$  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 has 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):

$$z = a_1x^2 + a_2y^2 + a_3xy + a_4x + a_5y + a_6 \quad (1)$$

$$z = a_1 + a_2x + a_3x^2 + a_4x^3 + a_5y + a_6y^2 + a_7y^3 + a_8y^4 + a_9y^5 \quad (2)$$

$$z = a_1 + a_2\log(x) + a_3\log(x)^2 + a_4\log(x)^3 + \frac{a_5}{y} + \frac{a_6}{y^2} + \frac{a_7}{y^3} + \frac{a_8}{y^4} + \frac{a_9}{y^5} \quad (3)$$

z - casting speed, m / min

x - steel temperature at casting [ $^{\circ}\text{C}$ ], for all correlations;

y - cooling water flow in zone 1 [l / min], for the correlations in Figures 1, 2 and 3;

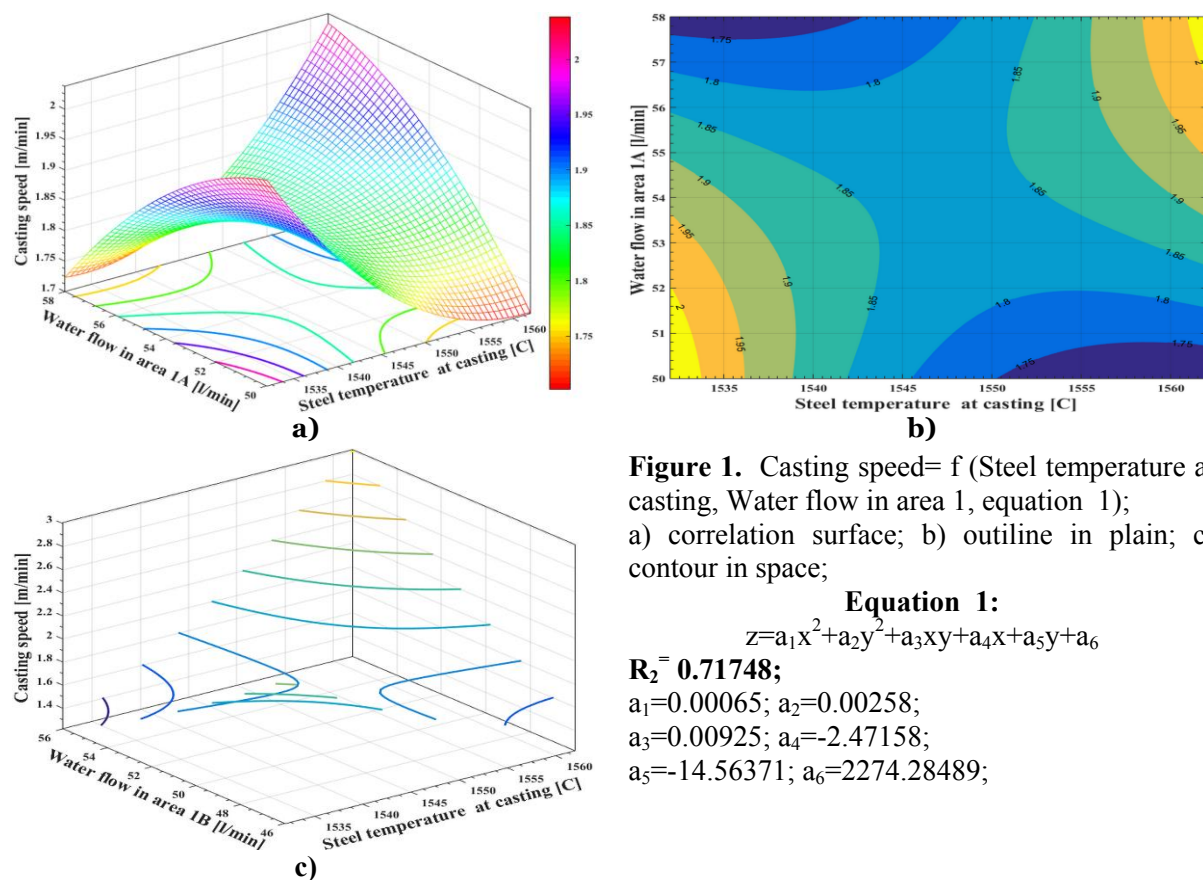
y - cooling water flow in zone 2 [l / min], for the correlations in Figures 4, 5 and 6;

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



**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:

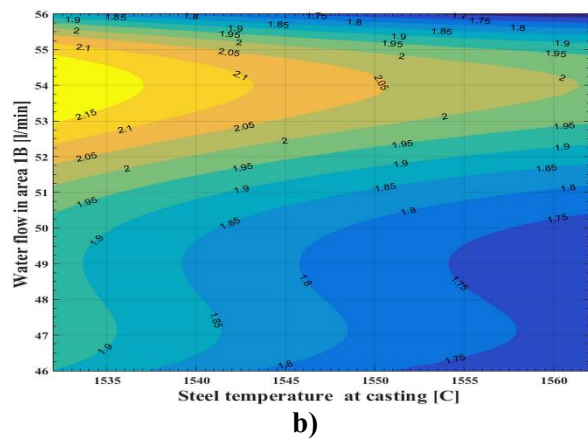
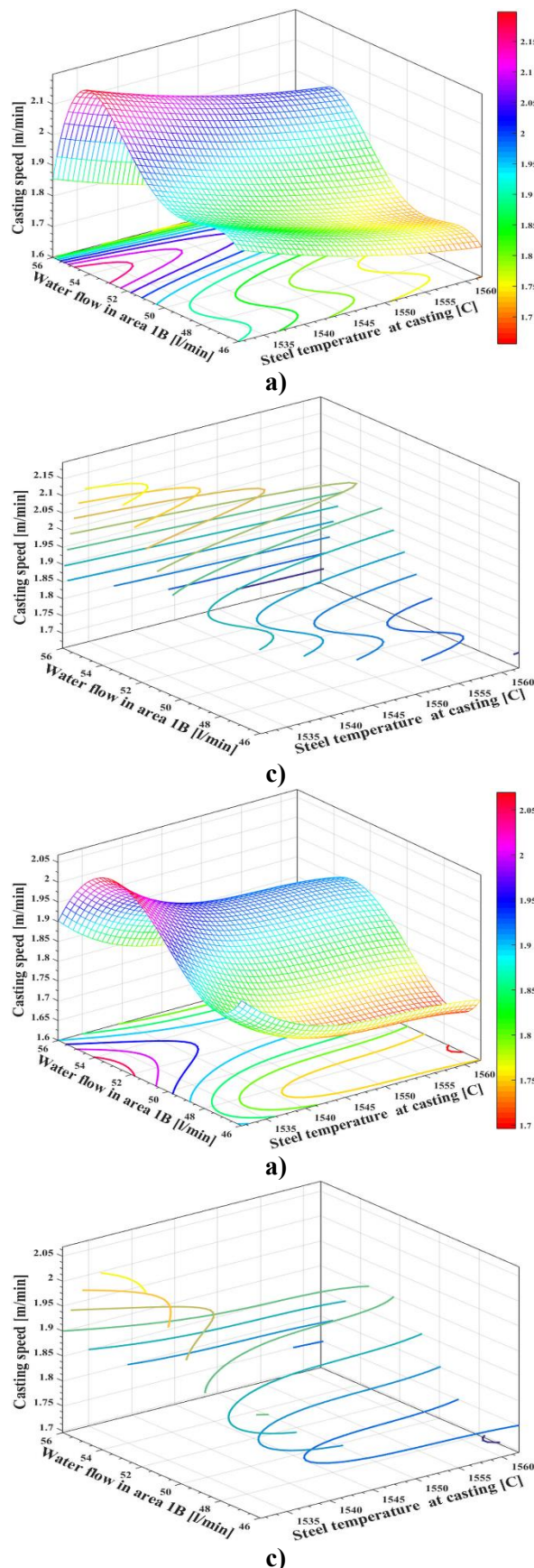
$$z = a_1x^2 + a_2y^2 + a_3xy + a_4x + a_5y + a_6$$

$$R_2 = 0.71748;$$

$$a_1 = 0.00065; a_2 = 0.00258;$$

$$a_3 = 0.00925; a_4 = -2.47158;$$

$$a_5 = -14.56371; a_6 = 2274.28489;$$



**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:**

$$z = a_1 + a_2x + a_3x^2 + a_4x^3 + a_5y + a_6y^2 + a_7y^3 + a_8y^4 + a_9y^5$$

**$R^2 = 0.79421$ ;**  
 $a_1=0$ ;  $a_2=-1.59968$ ;  
 $a_3=0.00092$ ;  $a_4=0$ ;  
 $a_5=0$ ;  $a_6=3.71578$ ;  
 $a_7=-0.14897$ ;  $a_8=0.00223$ ;  
 $a_9=0$ ;

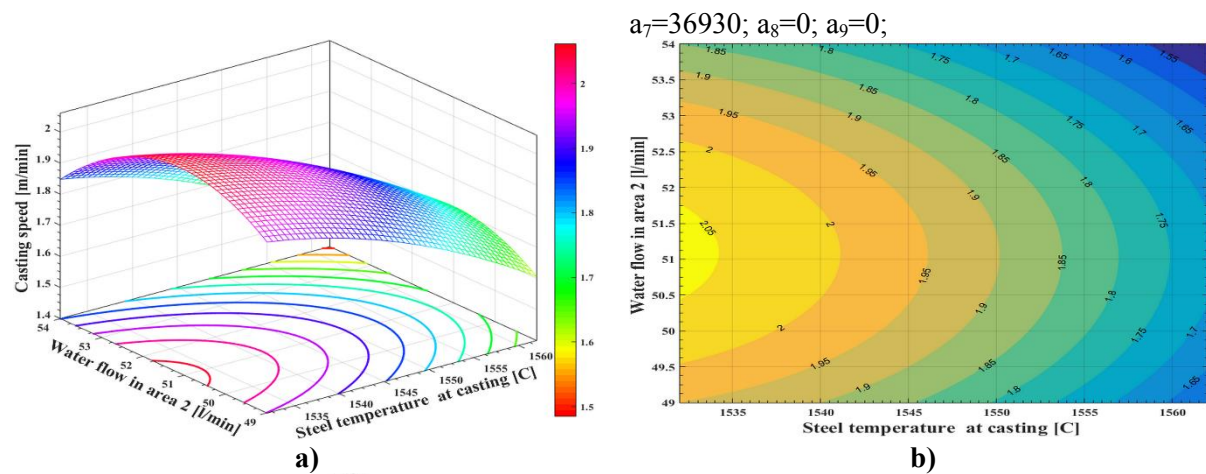
**Figure 3.** Casting speed= f (Steel temperature at casting, Water flow in area 1, equation 3); a) correlation surface; b) outline in plain; c) contour in space;

**Equation 3:**

$$z = a_1 + a_2 \log(x) + a_3 \log(x)^2 + a_4 \log(x)^3 + \frac{a_5}{y} + \frac{a_6}{y^2} + \frac{a_7}{y^3} + \frac{a_8}{y^4} + \frac{a_9}{y^5}$$

**$R^2 = 0.702100744917242$**   
 $a_1=21424$ ;  $a_2=-87475$ ;  
 $a_3=11905$ ;  $a_4=-54000$ ;  
 $a_5=44161$ ;  $a_6=-22154$ ;





**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:**

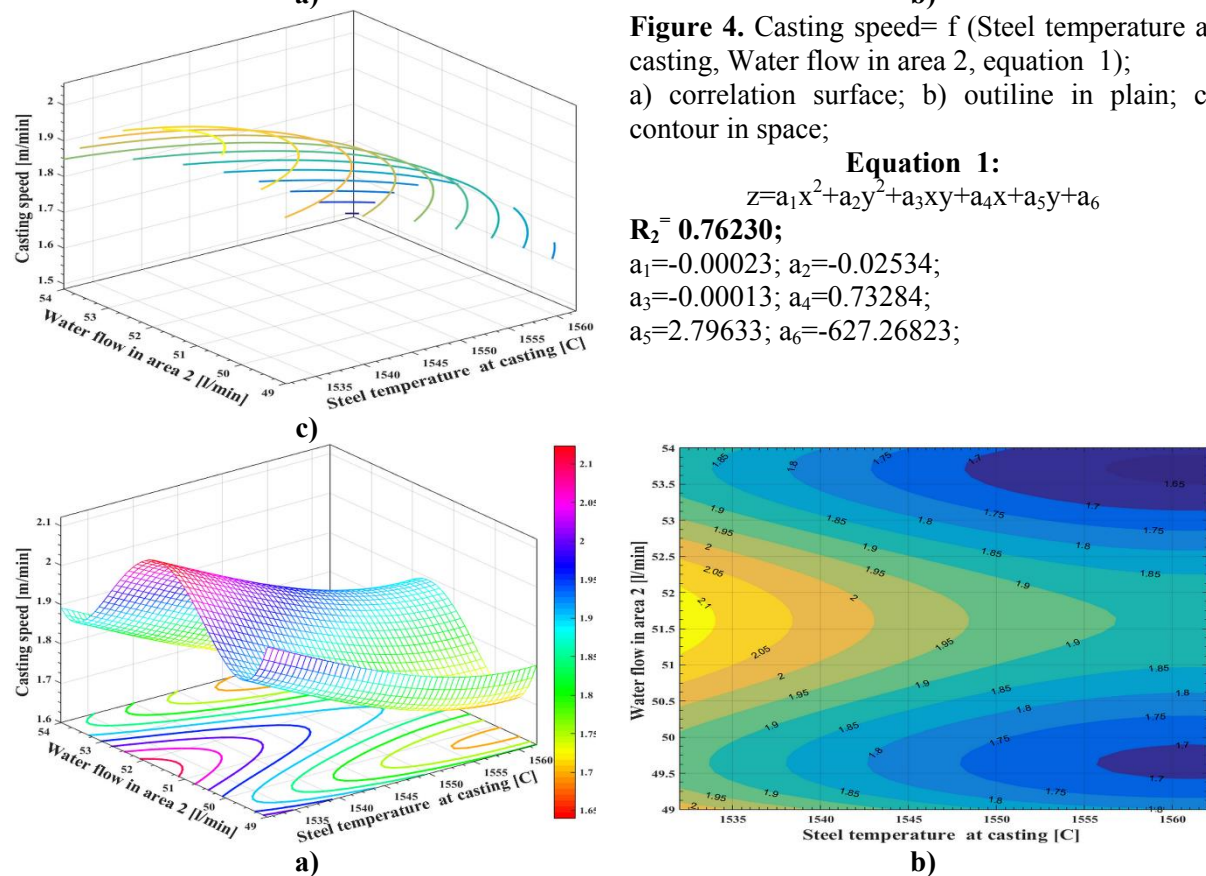
$$z=a_1x^2+a_2y^2+a_3xy+a_4x+a_5y+a_6$$

$$R_2 = 0.76230;$$

$$a_1=-0.00023; a_2=-0.02534;$$

$$a_3=-0.00013; a_4=0.73284;$$

$$a_5=2.79633; a_6=-627.26823;$$



**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:**

$$z = a_1+a_2x+a_3x^2+a_4x^3+a_5y+a_6y^2+a_7y^3+a_8y^4+a_9y^5$$

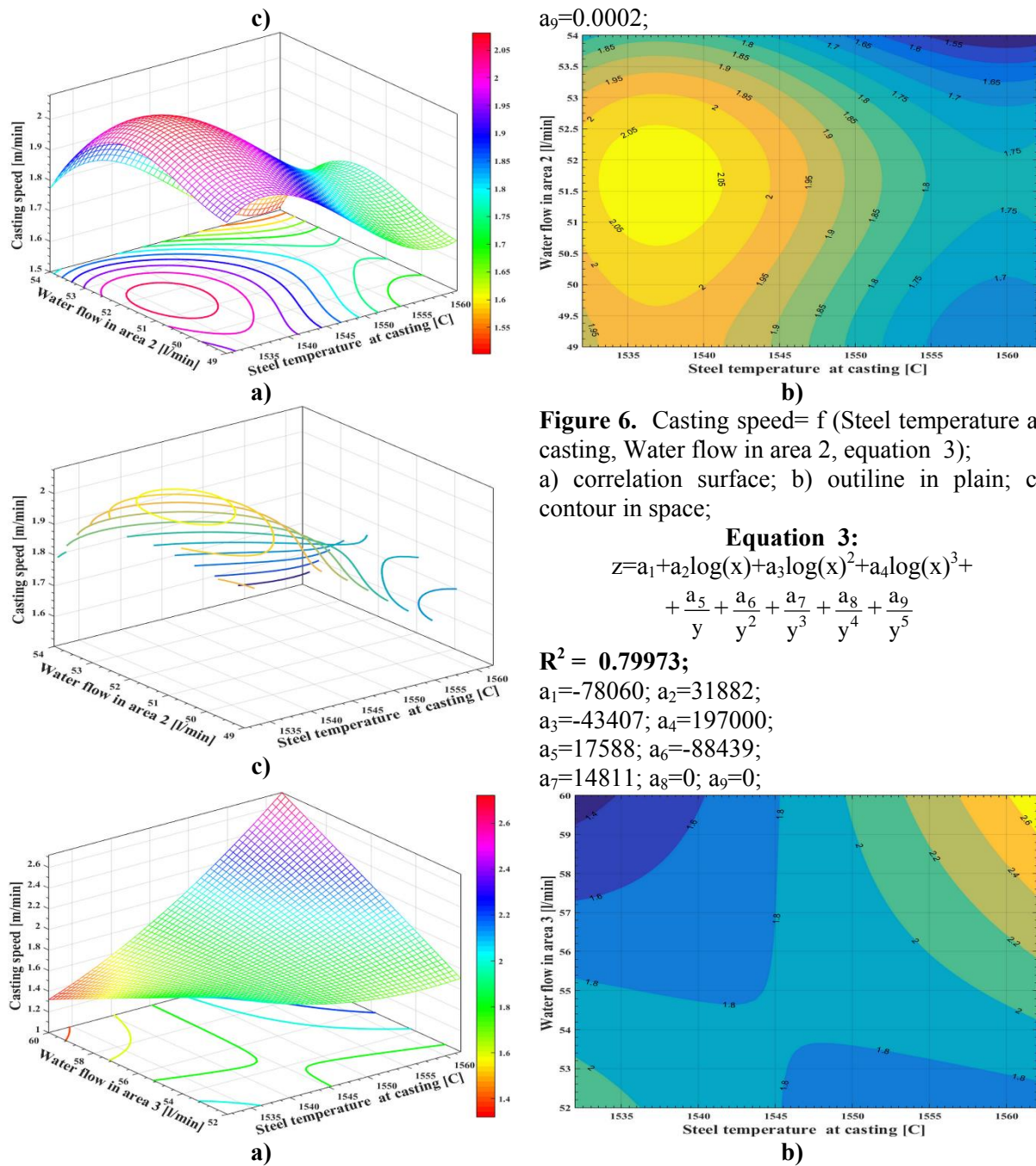
$$R^2 = 0.86142;$$

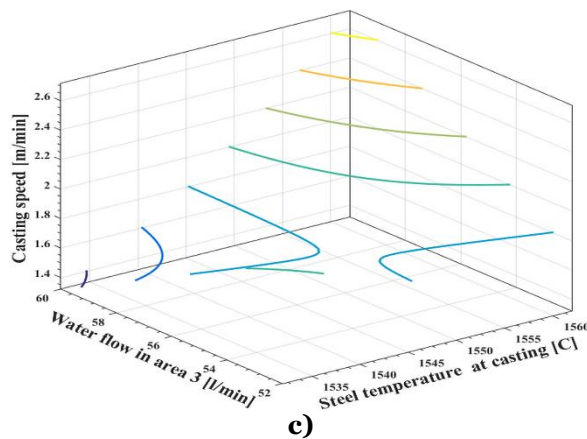
$$a_1=0; a_2=36.64747;$$

$$a_3=-0.02389; a_4=0;$$

$$a_5=0; a_6=-70.41481;$$

$$a_7=2.72890; a_8=-0.03963;$$





**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:**

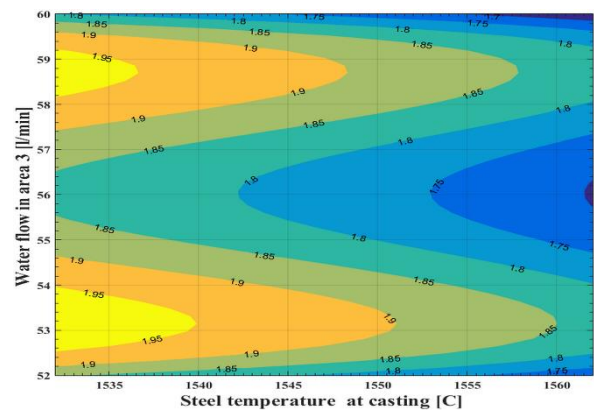
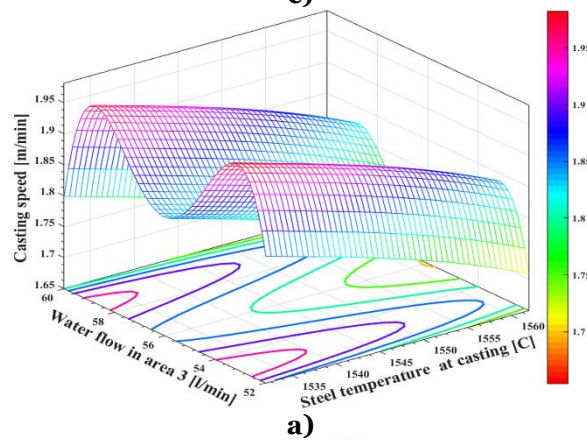
$$z = a_1x^2 + a_2y^2 + a_3xy + a_4x + a_5y + a_6$$

$$R^2 = 0.68311;$$

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

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

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



**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:**

$$z = a_1 + a_2x + a_3x^2 + a_4x^3 + a_5y + a_6y^2 + a_7y^3 + a_8y^4 + a_9y^5$$

$$R^2 = 0.62121;$$

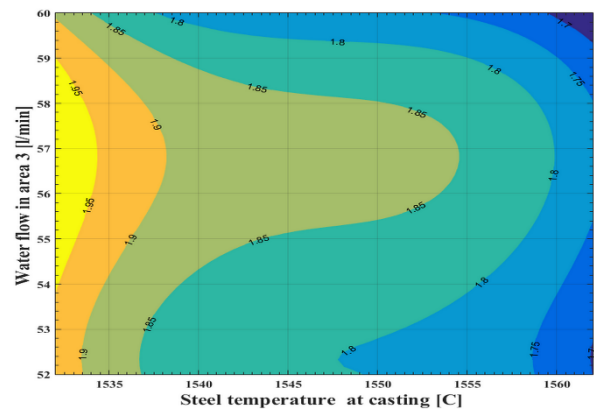
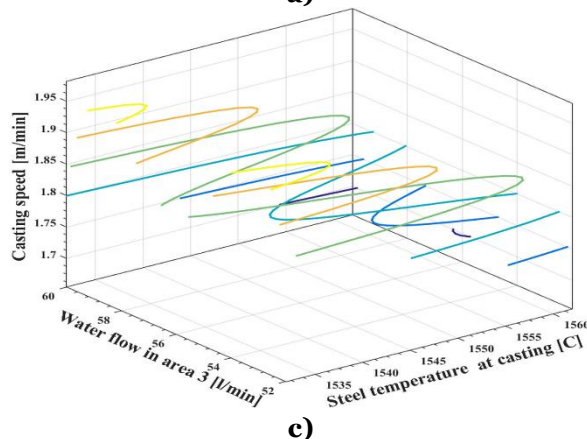
$$a_1 = 0; a_2 = -8.35244;$$

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

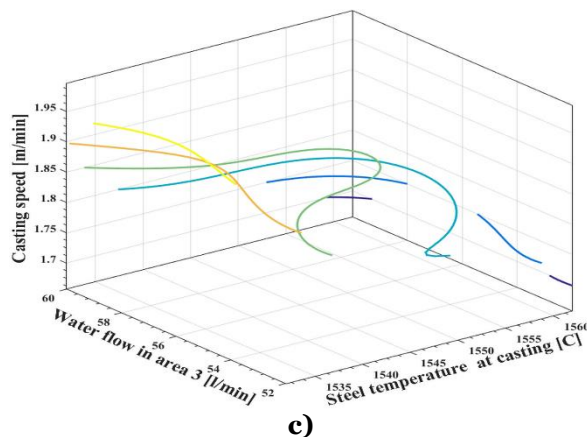
$$a_5 = 0; a_6 = 13.73756;$$

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

$$a_9 = 0;$$







**Figure 9.** Casting speed= f (Steel temperature at casting, Water flow in area 3, equation 3); a) correlation surface; b) outline in plain; c) contour in space;

**Equation 3:**

$$z = a_1 + a_2 \log(x) + a_3 \log(x)^2 + a_4 \log(x)^3 + \frac{a_5}{y} + \frac{a_6}{y^2} + \frac{a_7}{y^3} + \frac{a_8}{y^4} + \frac{a_9}{y^5}$$

$$R^2 = 0.55463;$$

$$a_1 = 44677; a_2 = -18249;$$

$$a_3 = 24848; a_4 = -113000;$$

$$a_5 = 38611; a_6 = -21071;$$

$$a_7 = 38268; a_8 = 0;$$

$$a_9 = 0;$$

#### 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 1.9m / min;

- Figure 6 at the same values for the aforesaid parameters, the casting speed is also 1.95m / 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  $\varnothing$  180mm.

#### Acknowledgment

This work was supported by a grant of the Romanian National Authority for Scientific Research and Innovation, CNCS – UEFISCDI, project number PN-II-RU-TE-2014-4-1788.

#### References

[1] Ardelean E, Ardelean M, Socalici A and Heput T 2007 Simulation of continuous cast steel

- product solidification, *Revista de Metalurgia* **43** (3) 181-187
- [2] Bouhouch S, Lahreche M, Moussaoui A and Bast J 2007 Quality Monitoring Using Principal Component Analysis and Fuzzy Logic. Application in Continuous Casting Process, *American Journal of Applied Science* **4**(9) 637-644
- [3] Cioată V G 2008 Determination of the moulding time of alloys processed in a semi-solid state, *Metalurgia International* **13** (12) 42-52
- [4] Efimov V A 1986 *Casting and crystallizing of steel*, Ed. Technical, Bucuresti
- [5] Kiflie B and Alemu D 2000 *Thermal Analysis of Continuous Casting Process*, 5th Annual Conference on Manufacturing & Process Industry, Faculty of Technology, Addis Ababa University, Ethiopia
- [6] O'Conner T and Dantzig J 1994 Modeling the Thin Slab Continuous Casting Mold, *Metallurgical and Materials Transactions* **25B**(4) 443-457
- [7] Pinca C and Tirian G O 2006 *The numerical analysis of the asymmetrical thermal tension from hot rolling mill cylinders*, National Conference of Metallurgy and Materials Science, Bucuresti, Romania, pp 296-303
- [8] Singh J and Ganesh A 2008 Design and Analysis of GA based Neural/Fuzzy Optimum Adaptive Control, *Transactions on Systems and Control* **5** (3)
- [9] Tirian G O, Gheorghiu C A, Hepuț T and Rob R 2016 Fuzzy control strategy for secondary cooling of continuous steel casting, *IOP Conf. Ser.: Mater. Sci. Eng.* **200** 012046
- [10] Tirian G O, Gheorghiu C A, Hepuț T and Chioncel C 2016 Control system of water flow and casting speed in continuous steel casting, *IOP Conf. Ser.: Mater. Sci. Eng.* **200** 012047