ANNALS OF THE FACULTY OF ENGINEERING HUNEDOARA
2004, Tome II, Fascicole 2

CONTRIBUTIONS REGARDING THE INFLUENCE OF MICRO-COOLERS OVER THE PLASTICITY CHARACTERISTICS OF CARBON STEEL

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KEYWORDS:
steel, micro-coolers, ingot, casting

ABSTRACT

In this work are presented the obtained results regarding the influence of micro-coolers over the mechanical properties of carbon steel. The obtained experimental data were processed using SIDHD5 and MATLAB computer programs, resulting a series of equations with multiple correlations between steel mechanical properties and the casting temperature, specific quantity of micro-coolers and their dimensions. The resulted diagrams allowed the establishment of optimal technological variation fields of studied parameters for obtaining superior mechanical characteristics, which lead to the obtaining of steel ingots with properties and mechanical characteristics superiors to that of ordinary cast steel ingots.

1. INTRODUCTION

In order to study the influence of micro-coolers over the mechanical characteristics of steel it was used the method of introduction in the chill mould, in the same time with the casting, of the micro-coolers in granular shape. The stimulations of heterogeneous germination, on surface generated by particles introduced in the center of the liquid ingot, lead to the formation of a secondary solidification front and of heat absorption in this zone.

By introduction of micro-coolers in liquid steel from chill mould it was desired to produce in the central zone of ingot of an increased number of crystallization centers, having as basis the Efimov statement [1] that one grinding procedure of the structure in the axial zone is its intense mixing under the action of some external factors or by introductions of artificial crystallization grains. So, the granules are for a time period in suspension in melted steel and cause some effects at steel cooling and solidification: cooling, crystallizing, alloying, obtaining of some special physical properties. The used micro-coolers need to fulfill a series of conditions: spherical shape or close to it, reduce content of noxious impurities, high bulk density and reduce cost comparatively to the steel one [2].

2. EXPERIMENTAL RESULTS

The experiments were made for a carbon steel, grade OLC 45, from which it were cast ingots having the mass 9 tones, with micro-coolers addition in specific quantities of 1kg/t, 1.5 kg/t, 2 kg/t, 3kg/t and 4 kg/t, having the dimensions ranging between 2 - 6 mm. The granules have been introduced in the chill moulds at 30%, 60%, respectively 90% filling of the chill mould. From every ingot it have been taken samples for establishing physical-mechanical properties.

By processing the obtained data from the experiments using SIDHD5 and MATLAB computer programs we obtained a series of equations with multiple correlations of second order between the dependent parameters: percentage elongation after failure (A_5, [%]) and necking coefficient (Z, [%]) and three independent parameters: the micro-coolers dimensions (d, [mm]), micro-coolers quantity (m, [kg/t]) and casting temperature (t, [°C]). For each equation it were determined the average values of the fallowed parameters, dispersion, standard deviation, stationary point values, correlation coefficient value and standard error value.

The multiple correlations (with three parameters) allowed the establishing of some equations between a qualitative parameter (dependent parameter) and three independent parameters. For graphical representation need to consider one of three parameters to be constant, therefore it were given alternatively values to these parameters, namely they have been considered equal to average value after which it were made graphical representations.

The equation of the regressing hyper-surface for seeming yielding limit (A_5) is:

$$A_5 = -0{,}5567 \cdot m^2 + 0{,}06035 \cdot d^2 + 9{,}121 \cdot 10^{-6} \cdot t^2 - 0{,}5331 \cdot m \cdot d - 0{,}0001736 \cdot d \cdot t + 0{,}004736 \cdot t \cdot m - 0{,}003318 \cdot m + 0{,}0003761 \cdot d - 1{,}069 \cdot 10^{-6} \cdot t + 2{,}344 \cdot 10^{-6};$$
$$R^2 = 0{,}9812; \quad (1)$$

The equations of regress surfaces for A_5 (fig.1, fig.2, fig.3) in case when constant parameter is added micro-coolers quantity, micro-coolers diameter respectively casting temperature, in case of directing of steel ingot solidification are:

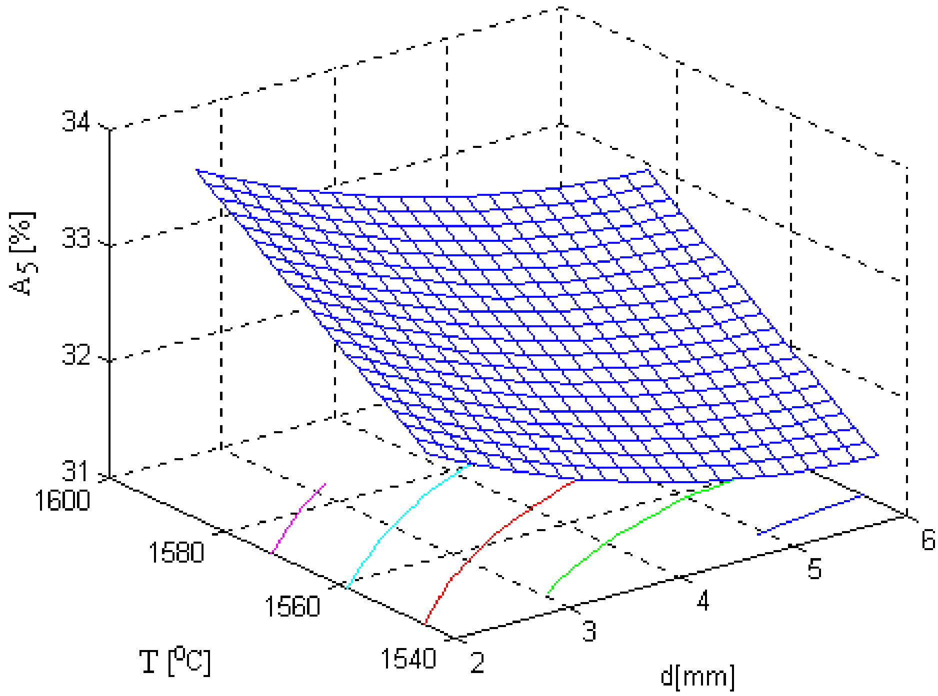
$$A_5 = 0{,}06035 \cdot d^2 + 9{,}121 \cdot 10^{-6} \cdot t^2 + 0{,}0001736 \cdot d \cdot t - 1{,}021 \cdot d + 0{,}009078 \cdot t - 2{,}051; \quad (2)$$
$$A_5 = -0{,}5567 \cdot m^2 + 9{,}121 \cdot 10^{-6} \cdot t^2 + 0{,}004736 \cdot t \cdot m - 2{,}136 \cdot m + 0{,}0006956 \cdot t + 0{,}9671; \quad (3)$$
$$A_5 = -0{,}5567 \cdot m^2 + 0{,}06035 \cdot d^2 - 0{,}5331 \cdot m \cdot d + 7{,}408 \cdot m + 0{,}2721 \cdot d + 22{,}34; \quad (4)$$

The equation of the regressing hyper-surface for tensile strength (Z) is:

$$Z = -0{,}548 \cdot m^2 - 0{,}03047 \cdot d^2 + 0{,}00002312 \cdot t^2 - 0{,}02422 \cdot m \cdot d - 0{,}00004905 \cdot d \cdot t + 0{,}00344 \cdot t \cdot m - 0{,}0001488 \cdot m - 0{,}0001898 \cdot d - 7{,}688 \cdot 10^{-8} \cdot t - 1{,}183 \cdot 10^{-6};$$
$$R^2 = 0{,}9974 \quad (5)$$

The equations of regress surfaces for Z (fig.4, fig.5, fig.6) in case when constant parameter is added micro-coolers quantity, micro-coolers diameter respectively casting temperature, in case of directing of steel ingot solidification are:

$$Z = 0{,}03047 \cdot d^2 + 0{,}00002312 \cdot t^2 - 0{,}00004095 \cdot d \cdot t - 0{,}0559 \cdot d + 0{,}007912 \cdot t - 2{,}899; \quad (6)$$
$$Z = -0{,}548 \cdot m^2 + 0{,}00002312 \cdot t^2 + 0{,}00344 \cdot t \cdot m - 0{,}09704 \cdot m + 0{,}0001637 \cdot t - 0{,}4883; \quad (7)$$
$$Z = -0{,}548 \cdot m^2 - 0{,}03047 \cdot d^2 - 0{,}02422 \cdot m \cdot d + 5{,}383 \cdot m + 0{,}0639 \cdot d + 56{,}62; \quad (8)$$



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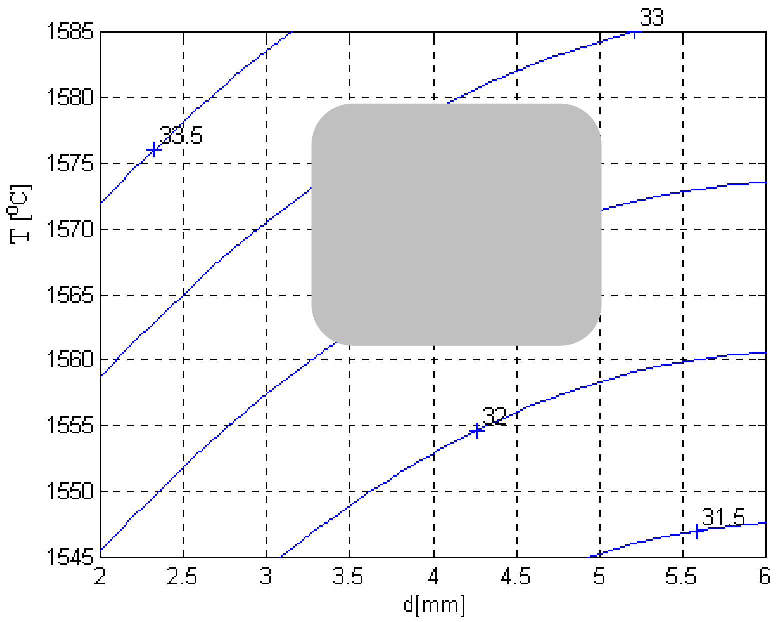
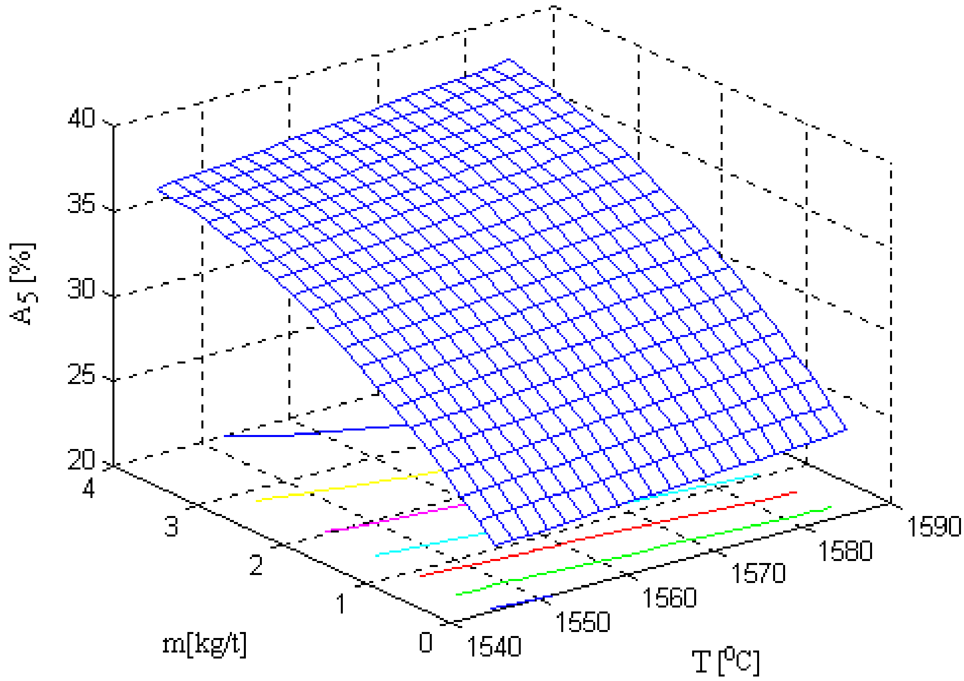


b.

FIG.1. REGRESSION SURFACE A_5 (A); CONTOUR LINES OF TECHNOLOGICAL DOMAINS FOR DIFFERENT INTERVALS OF CASTING TEMPERATURE AND MICRO-COOLERS DIAMETER (B).



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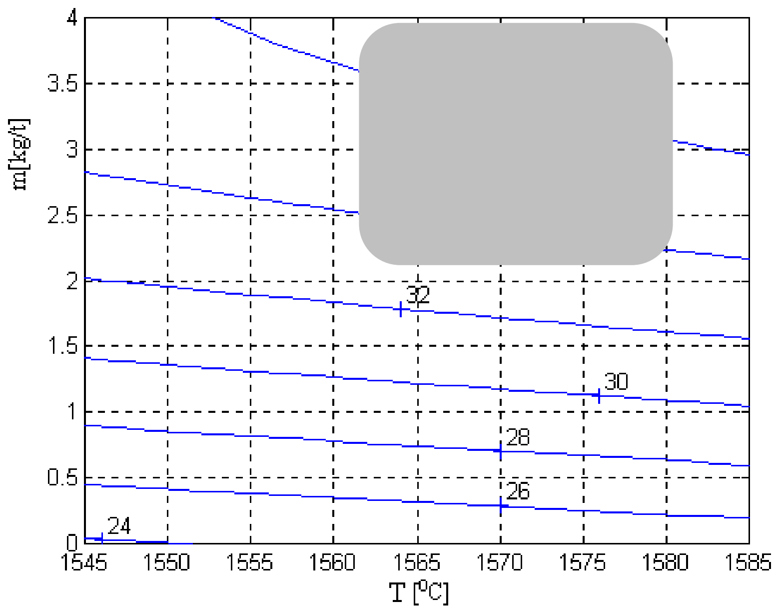

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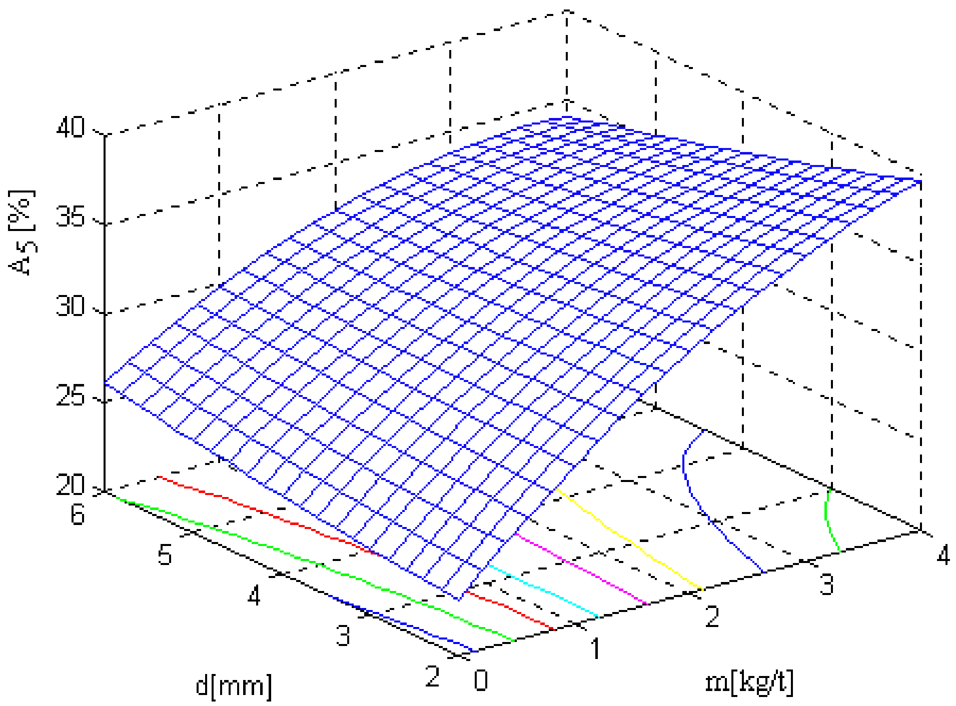
FIG.2. REGRESSION SURFACE A_5 (A); CONTOUR LINES OF TECHNOLOGICAL DOMAINS FOR DIFFERENT INTERVALS OF ADDED MICRO-COOLERS QUANTITY AND CASTING TEMPERATURE (B).



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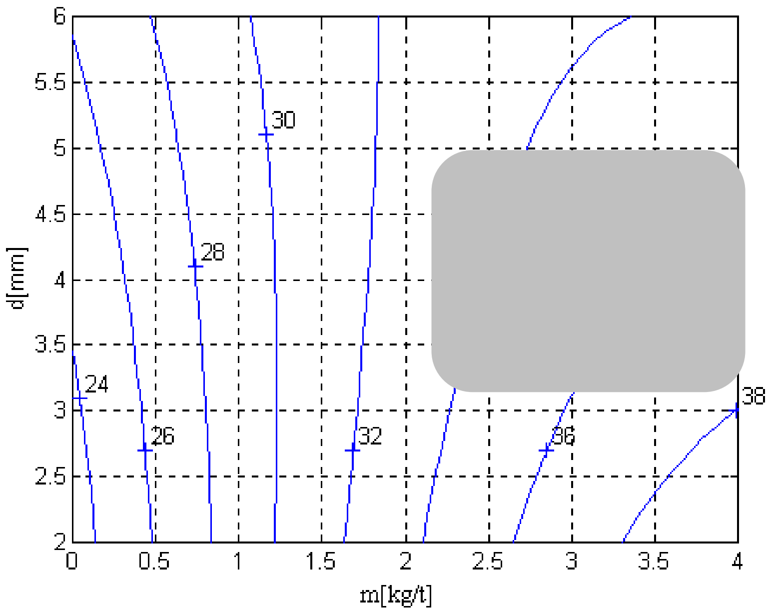

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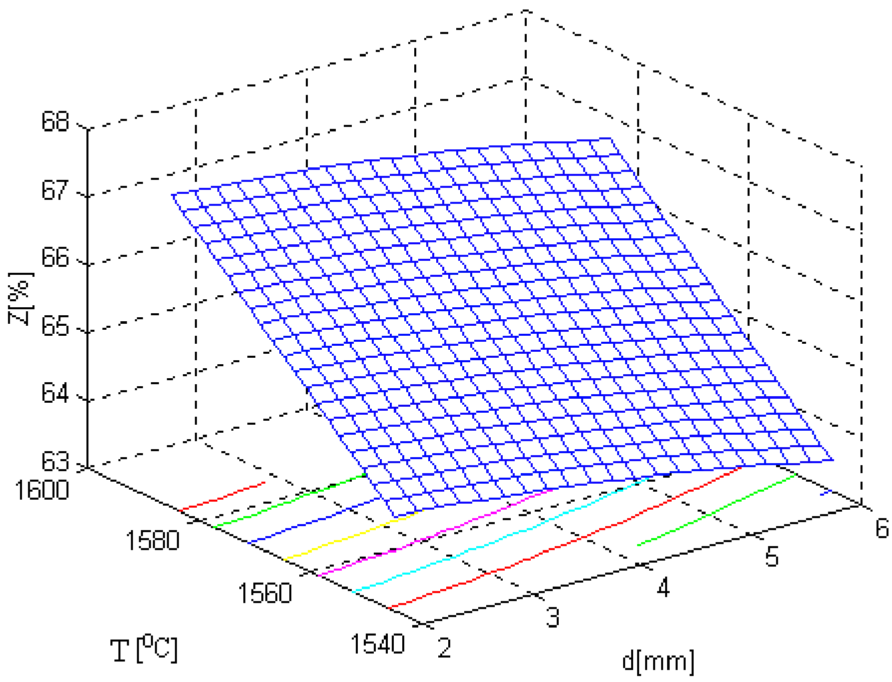
FIG.3. REGRESSION SURFACE A_5 (A); CONTOUR LINES OF TECHNOLOGICAL DOMAINS FOR DIFFERENT INTERVALS OF ADDED MICRO-COOLERS QUANTITY AND MICRO-COOLERS DIAMETER (B).



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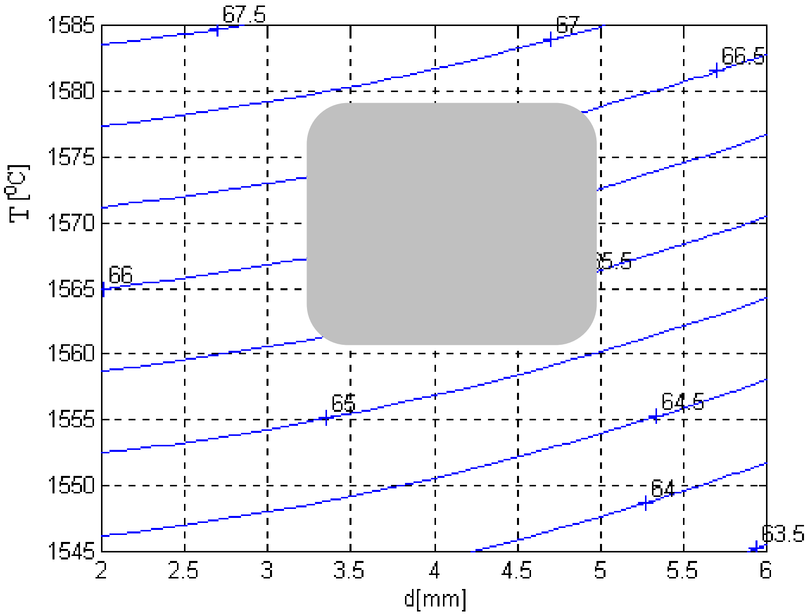
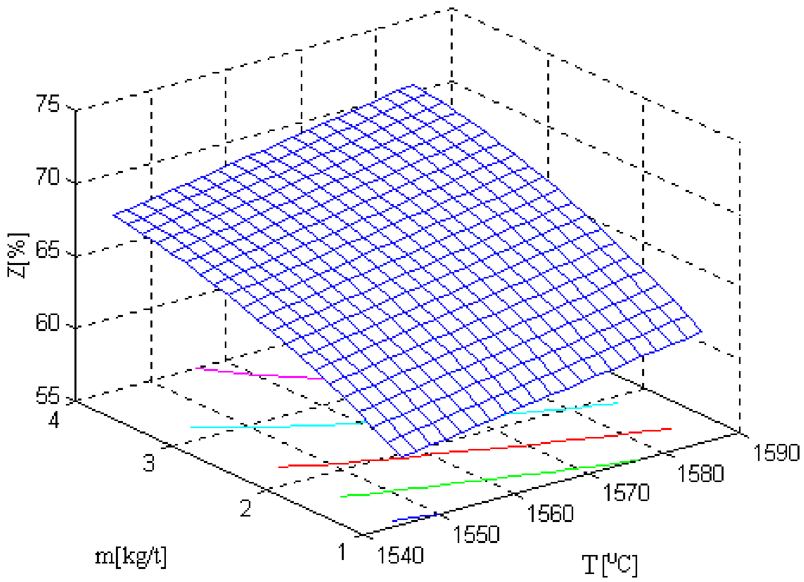


b.

FIG.4. REGRESSION SURFACE Z (A); CONTOUR LINES OF TECHNOLOGICAL DOMAINS FOR DIFFERENT INTERVALS OF CASTING TEMPERATURE AND MICRO-COOLERS DIAMETER.

These graphical representations allow the establishing of variations sub-domains for independent parameters so that to obtain the desired values for dependent parameters. In cases when regress surfaces have a stationary point it exist two sub-domains, and it is obvious that in practice it is chosen the most convenient from technological point of view.



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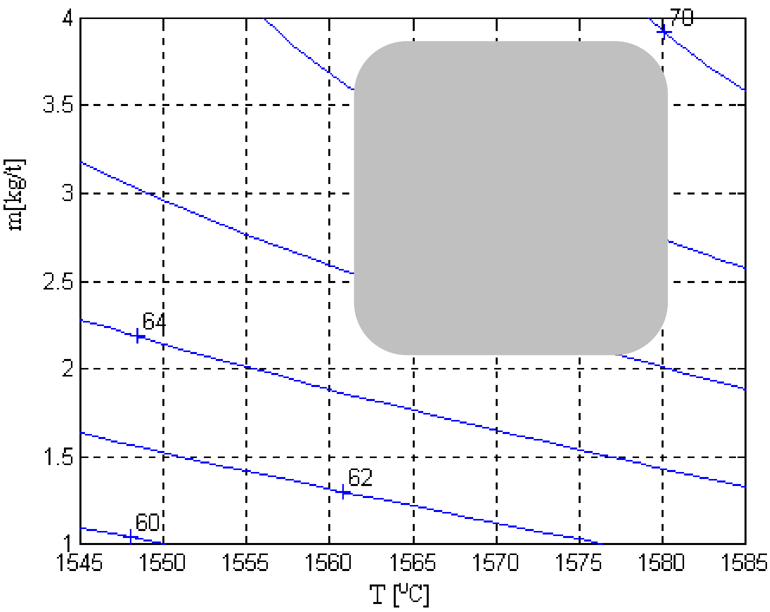

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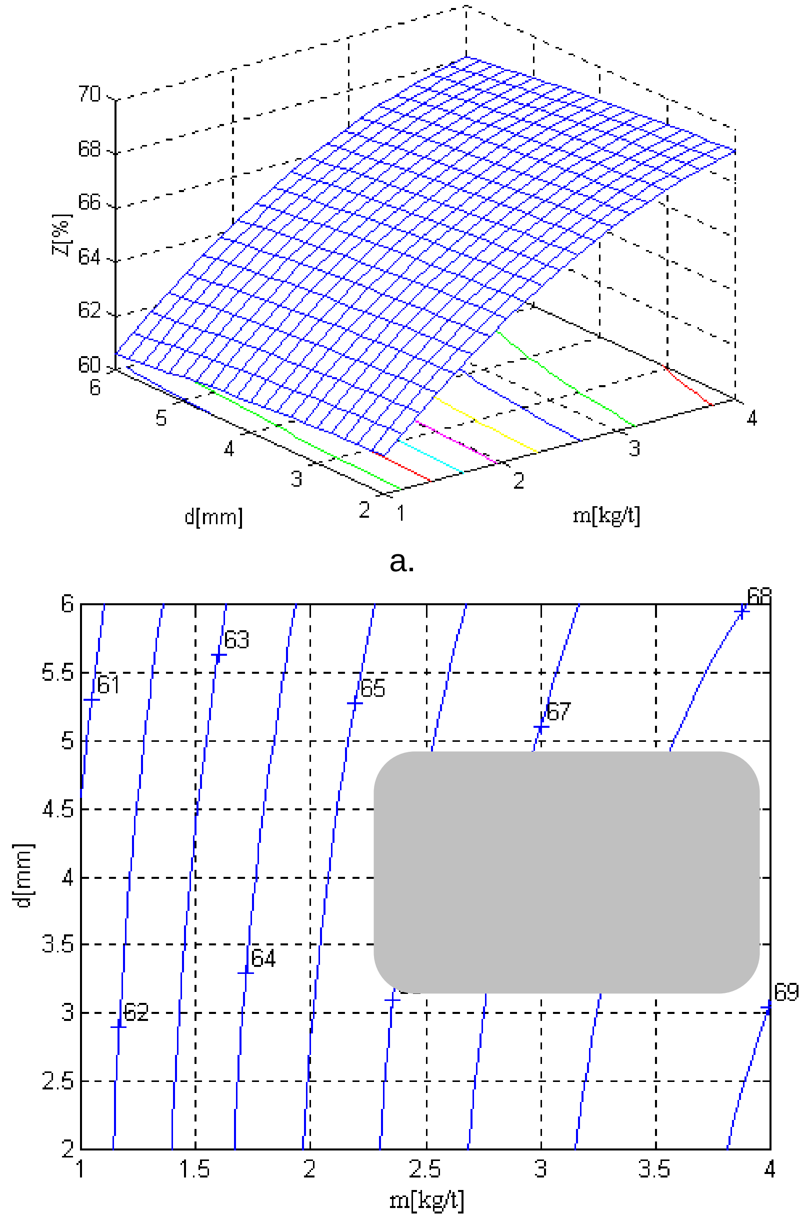
FIG.5. REGRESSION SURFACE Z (A); CONTOUR LINES OF TECHNOLOGICAL DOMAINS FOR DIFFERENT INTERVALS OF ADDED MICRO-COOLERS QUANTITY AND CASTING TEMPERATURE.

3. CONCLUSIONS

Analyzing the equations with multiple correlations and the obtained regress surfaces it is observed increasing and a significant homogeneity of mechanical characteristics.

The optimum variation field for independent parameters: casting temperature it is between 1560-1580°C, specific micro-coolers consumptions used for directing of solidification is between 2-4 kg/t, and micro-coolers diameter vary between 3-5 mm.

The applying of this technology allow the substantial increasing of homogeneity and spreading degree of pine-tree structure, decreasing of length and width of developing zone of chemical non-uniformity as well as of sulfide placed at the boundary of primary grains, reduction of segregation and gases content.



a.

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FIG.6. REGRESSION SURFACE Z (A); CONTOUR LINES OF TECHNOLOGICAL DOMAINS FOR DIFFERENT INTERVALS OF ADDED MICRO-COOLERS QUANTITY AND MICRO-COOLERS DIAMETER.

4. REFERENCES

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