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SIMULATION TENDENCIES IN THE CONTINUOUSLY CAST HALF-PRODUCTS AREA

Abstract:

Primordial method for the decrease of the superheat of the steel of the in of the crystallizer, consist in the introduction of consumable micro-coolers, which can be exterior or internal.

The mathematical molding of the solidification and cooling phenomenon of continuously cast half-products, presented the in afterwards, is based on the mathematical description of phenomenon. This solution problem is, practically, the heat solving equation in of non-steady regime. For defined the heat conduction between half-product and crystallizer is necessary the cognition of initial conditions, the variation law of the heat flux between half-product – crystallizer and the heat flux between crystallizer – cooling water.

In this paper is presented simulation solidification model of steel continuous casting, using finite element model. For this is considered a section in mould-continuous casting system. This section is divided with discreet element structure. Using these experiments is made graphical dependents of temperature in some different point from surface crust to center of half-product, and also solidification speed for S235 (OL37) steel.

Keywords:

continuous casting, steel, solidification

INTRODUCTION

The metallurgical industry from Romania is structured in way echeloned assured necessary of iron metallurgical products of the economic branches, and in order to participate at the international changes of products from steels in the sight compensation of the import of prime materials.

The management in metallurgy must be find answers in current stage, to another two questions, which operates more criteria in the practice of the exploitation method.

- *What technical-organizational solutions to adopted the in the classic technology in order to growth of the cast productivity, accomplished the quality metallurgical products (the maximal productivity criteria)*
- *What sizes of continuously cast half-products to adopted the in manufacturing process, in order to appropriate the final form, accomplished this quality (the dimensional criteria)*

Obviously, all these criteria's are subordinate by-path of primordial interest of the metallurgy's *managers, namely the good qualities manufactured products at the minimal costs.*

The main task of the continuous cast is improved of continuous cast steel quality. In order to assured the solidification conditions imposed by the steel chemical composition must be synchronize a numerous technological factors, the most important be the steel chemical composition, the casting temperature and speed of drawing.

Primordial method for the decrease of the superheat of the steel of the in of the crystallizer, consist in the introduction of consumable micro-coolers, which can be exterior or internal. The exterior micro-coolers can be prepared out of the system and entered the crystallizer, and the internal micro-coolers are constituted from steels crusts, immediate format in the core of the half-products, on the water cooled surfaces. The outside micro-coolers can be entered in the liquid steel below different forms: small shots, granules or particles, draw-bars, wire, tube, etc. The addition of micro-coolers in crystallizer drives to the growth of the zone of the echi-axial crystals, diminish the degree of superheat and reduce the axial porosity.

The mathematical molding of the solidification and cooling phenomenon of continuously cast half-products, presented the in afterwards, is based on the mathematical description of phenomenon. This solution problem is, practically, the heat solving equation in of non-steady regime. For defined the heat conduction between half-product and crystallizer is necessary the cognition of initial conditions, the variation law of the heat flux between half-product – crystallizer and the heat flux between crystallizer – cooling water. Some conditions are can easy schematized, other only that drive to systems of which equations can be solved on analytic path.

THE PROGRAMM

The computer program is written in C++ and works under Win32 (i.e. Windows 95, 98, Me, NT4, 2000, XP – with Intel processor). For the graphic interface, the program uses MFC (Microsoft Foundation Classes), a class library that encloses the functional character of the standard programming interface Windows API – Application Program Interface. The source program has a modular, object-oriented architecture. One C++ module consists in general in a pair of files: one with the extension.H (form header) that contains function and/or class declarations, used as interface with the other modules, and one with the extension .CPP (from C++) that contains definitions (implementations of the functions and classes declared in the header). The other ones are auxiliaries of these or are meant to implement graphs, windows, dialogue cases, etc. The C standard functions (open (), or exit ()), which are not a Windows API components, uses other biblioteq, respectively MSVCRT (Microsoft Visual C Runtime). The 3D graphs are realized with the Windows implementation of OpenGL specification (Open Graphics Library). The dynamical biblioteq (MFC42.DLL, MSVCRT.DLL, OPENGL32.DLL and GLU32.DLL) are installed with the operating system.

For implementation of an algorithm of the above described model we need the fallowing initial data: ambient temperature, casting temperature, initial temperature of the crystallizer, number of nodes from half-finished product and from crystallizer with respect to both axes, values of thermal conductibility for steel and cupper function of temperature, values of enthalpy for steel and copper function of temperature. In case of steel this functional dependence need to include fusion latent heat; tapping condition of half-finished product from equipment; stopping condition of the algorithm. This could be: manual stopping, after a given time period, at a specified minimum, average, or maximum temperature of the half-finished product, maximum variation of enthalpy at an iteration.

The simulation is realized for a half-finished product (bloom), having the cross-section 240x270 mm, made of steel OL37-2K, according to the SR EN 10025 standard. The data are: the ambient temperature 20°C, the casting temperature 1550°C, the convection constant K = 15.

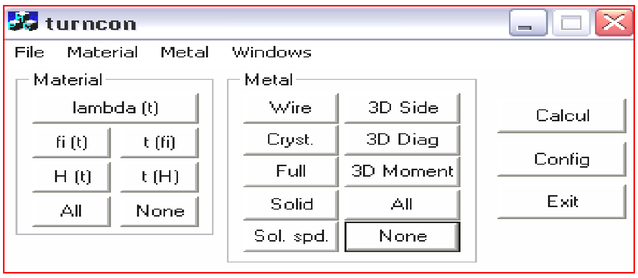

Fig. 1. The main window of the program

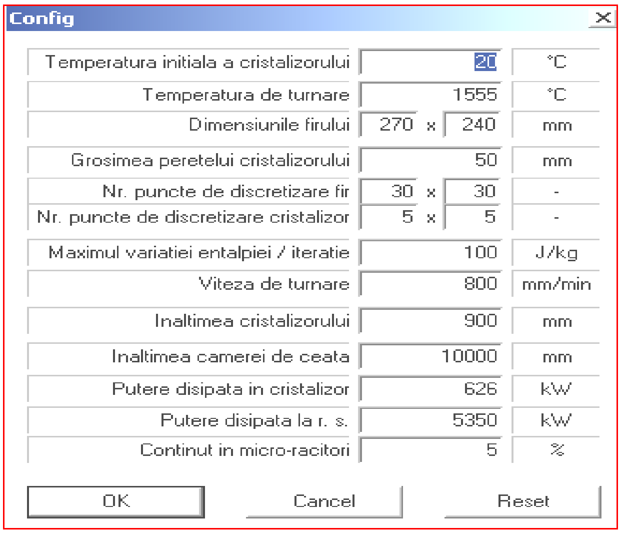

Fig. 2. The data input window

For configuration of specific dates for every steel grade, using the main interface (fig. 1.) the program opens the dialog box presented in fig. 2.

The simulation of the continuously cast half-products is effectuated in the case of 5% consumable micro-coolers introduced in crystallizer. The simulation is effectuated just for the primary and secondary cooling and not for the entire line of cast installation. Thus is explained the great values of the temperature of steel in the interior of the half-products (the middle layers) but which we diminish the feather below the value of the temperature solidus up to the moment which in the half-product is uttered.

With the number of knots of digitization is major (both the crystallizer and the half-product) and the maximum the variation of in an enthalpy in single iteration is less, the real time of simulation is major. In this case, the real time is 9h 8 min 44 s corresponding to the 13 min 21 s, in simulated time. The run of the program can be interrupted all moments, but with the mention as be start from same moment of time but must run the program from beginning. For illustrate the operation of the program, we accomplished captures of the screen to different moments of times, from which can obtain some information concerning the temperatures in the cast equipment, the real and simulated times.

The temperatures are indicated by the mean of a colored gradient, having the values: red for casting temperature, blue for ambient temperature and green for their average. Any intermediary temperature is a combination of these.

A first obtained dependence is represented by temperature variation of the half-finished product function of time (fig.6.). The distribution of the discredited points is also presented.

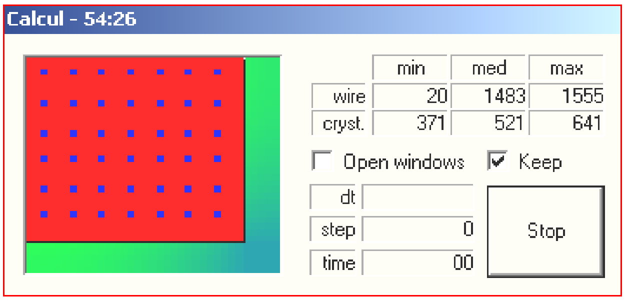

Fig. 3. The dialog window at 54min 26s (real time), respectivelly 0s (simulated time) (at the moment of the micro-coolers introduces)

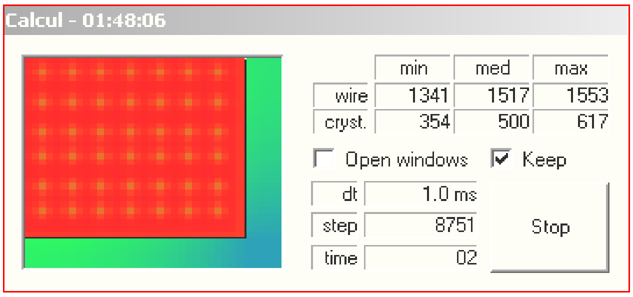

Fig. 4. The dialog window at 1h 48min 06s (real time), respectivelly 2s (simulated time)

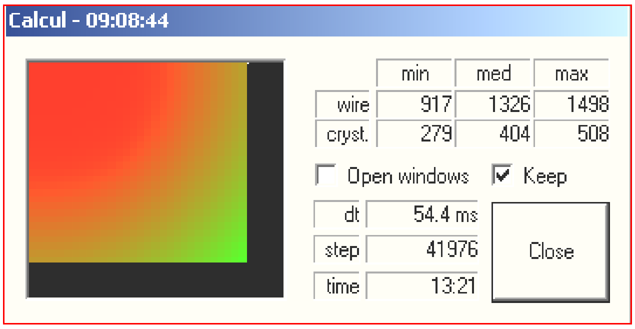

Fig. 5. The dialog window at 9h 8min 25s (real time), respectivelly 13min 21s (simulated time) (at the end of program simulation)

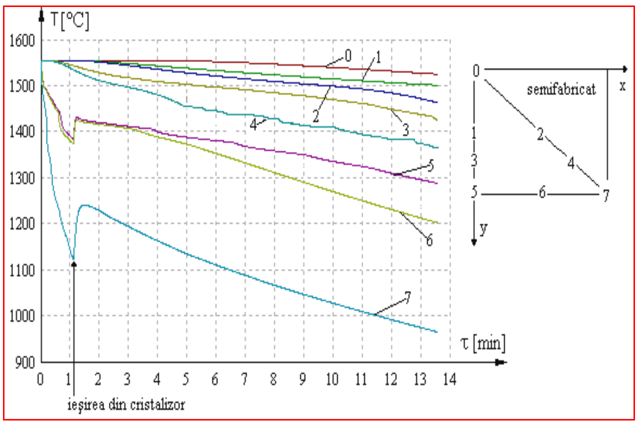

Fig.6. Temperature variation function of time

At a time moment (in the presented case equal with 1 min 7s), when it took place the driving out of considered surface from crystallizer, it took place an increasing of temperature in the superior layers of the half-finished product (with approximately 100°C in the corner and with 35…50°C in points 5 and 6 of the surface).

This increasing of the temperature is due to the lack of cooling of the wire immediately after the driving out from crystallizer to the firs ring of secondary cooling. After this moment the cooling and the solidification of the wire took place normally, the recorded temperatures corresponding to the measured ones.

It needs to be specified that the simulation was realized just for primary and secondary cooling, not for the entire running of the wire in the equipment. This explains steel's high temperature values in the interior of the half-finished product (middle layers), but they are decreasing under the solidus temperature value until the cutting of the half-finished product.

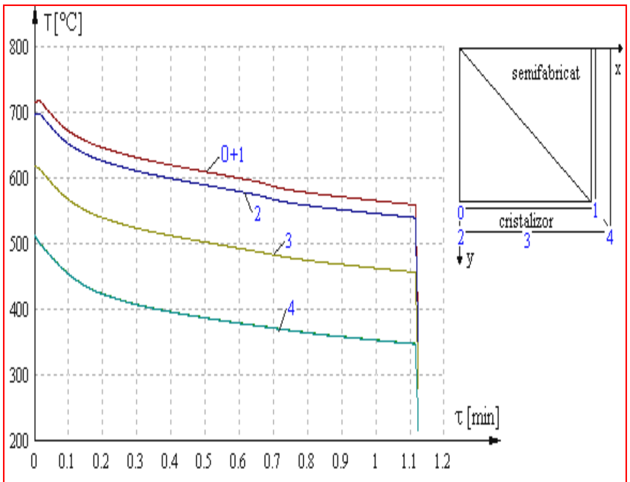

Fig.7. The temperature variation in the crystallizer, function of time

As regards the temperatures distribution in the crystallizer (which take over the heat transferred by the half-finished product and transfer it to the cooling water), it is presented in fig.7. In this case to it is presented also the position of the discredited points.

In the moment of the cast process beginning, in crystalizer (in discretized points), the temperatures are relative high. At 10s (simulated time) the temperature is between 350-600°C, and it is observed a slowly decreasing of the temperature of points placed near the center of the half-finished product, but also the variation mode of the temperature from layers closer to wire surface (320…550°C at 30s, 275…520°C at 1 min 7s, in final moment of simulation).

In fig. 8 the cumulate diagramme of the temperature are presented. It is observed the two cooling zone, respectivelly the primary cooling (when variated both the temperature in crystallizer and the cast line), and the secondary cooling (when only the cast line temperature is present). It was obtained variation type for the solidification speed, function of time. It refers to a solidification speed calculated between two consecutive iterations, fact that partially explain the oscillating aspect of the curves.

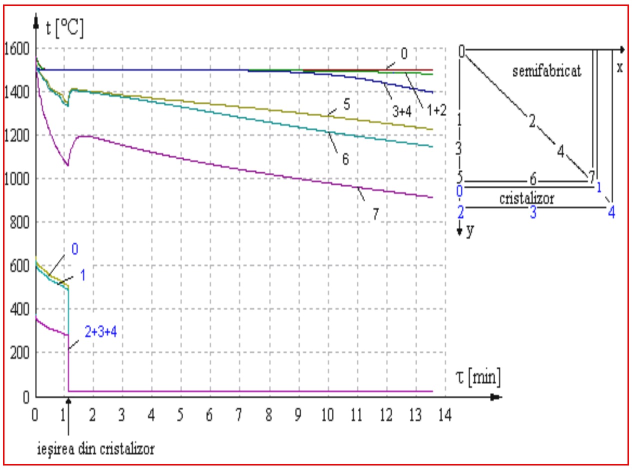

Fig. 8. The temperature variation in crystallizer and the cast line

Another type of temperature distribution, when the half-finished product is droved out from secondary cooling zone, it is presented in fig. 9…fig.13, at 3s, 9s, 24s, 30s and 60s, after introduced the micro-coolers.

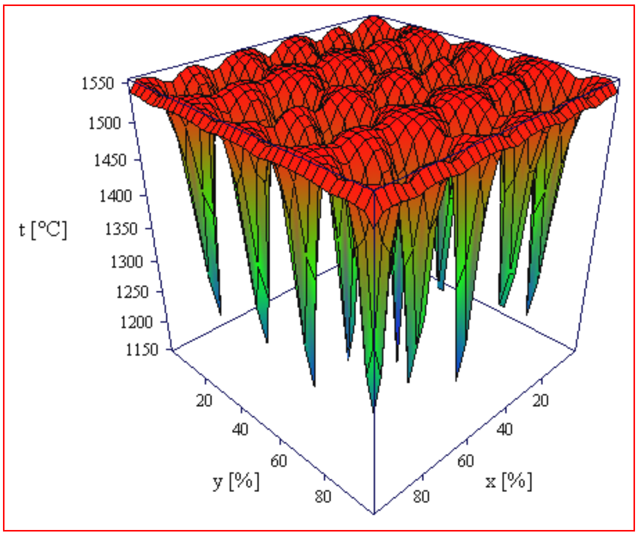

Fig. 9. The thermal field at 3s after the micro-coolers addition

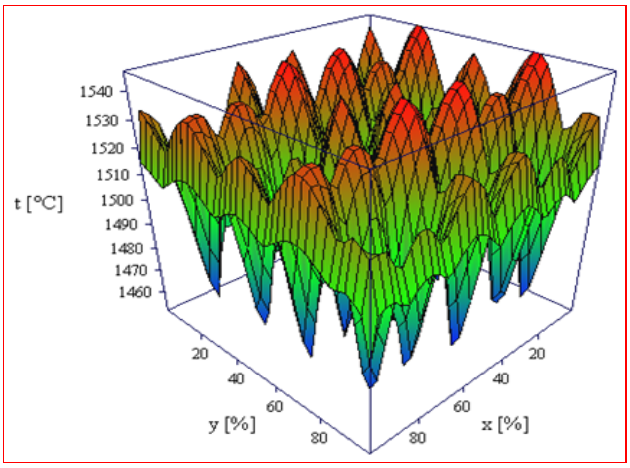

Fig. 10. Thermal field at 9s after the micro-coolers addition

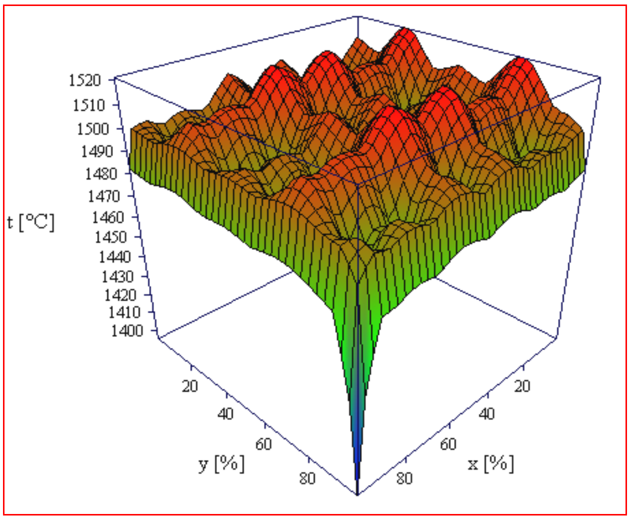

Fig. 11. Thermal field at 24s after the micro-coolers addition

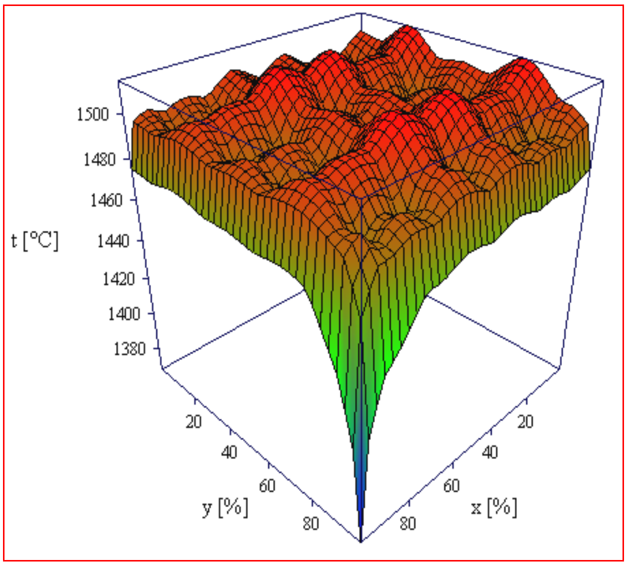

Fig. 12. The thermal field at 30s after the micro-coolers addition

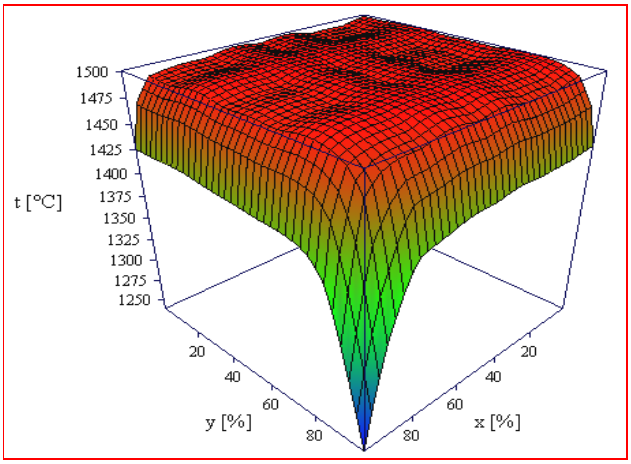

Fig. 13. The thermal field at 60s after the micro coolers addition

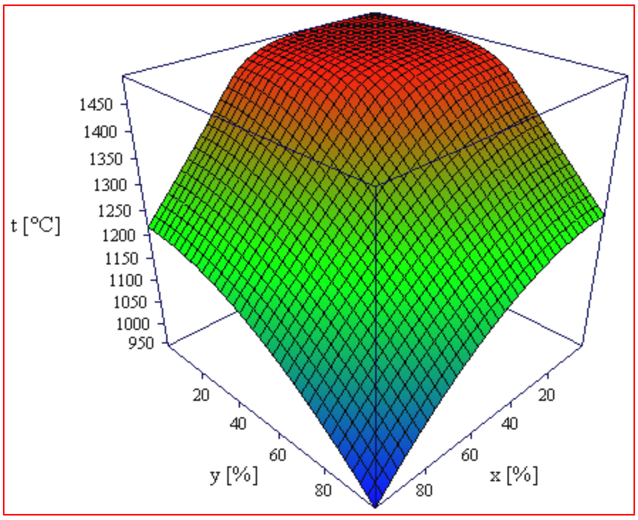

Fig. 14. The thermal field in half-product (with section 240x270mm) at 13 min 21s (simulated time)

The fig. 14 presents the thermal field in the half-product in the moment of the 13 min 21s (simulated time). The obtained regression surfaces corresponded from a quarter from the half-product section is like similarly of the other parts of the section. From the point of view of the temperature values, the half-product corner is the first cooled section, and the core is the most slowly cooled part.

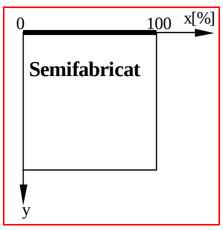

Fig. 15. The axe x for y = 0

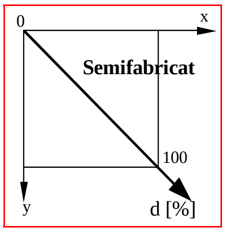

Fig.16. The diagonal

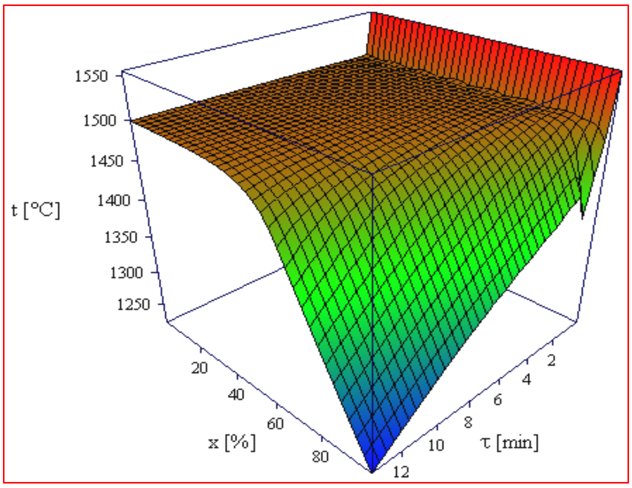

Fig. 17. The thermal field in half-product (240x270mm) across the axe x for y = 0, in time

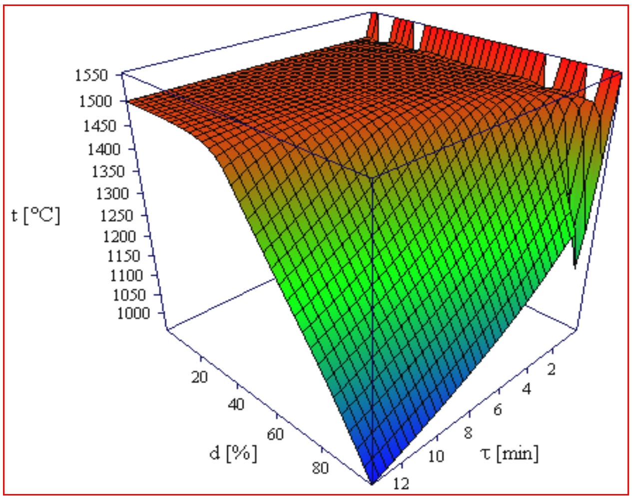

Fig. 18. The thermal field in half-product (section 240x270mm) across the diagonal, in time

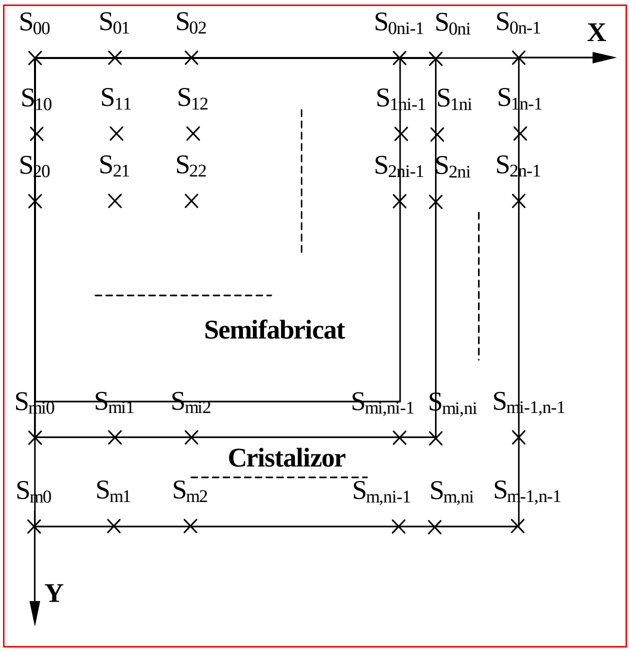

Fig. 19. The discretisation network

In order to realize a bi-dimensional mathematical modeling of a half-finished product it is considered a section of half-finished product-crystallizer assembly, which is divided using a discretisation network (fig.19). As results of the considered hypothesis, the half-finished product-crystallizer assembly is symmetric with respect to longitudinal axis of the half-finished product. The origin of the system of coordinates will be in the center of the half-finished product and the calculus will be made just for positive x and y.

The temperature of every node represents the mean temperature of node adjacent surface. In these nodes are written the finite differential equations presented above.

The model is realized based on the fallowing simplifying assumptions:

- *the heat transfer on longitudinal axis is neglected, considering that heat transfer take place just in horizontal section of the half-finished product*
- *the density variation is neglected*
- *the crystallizer section is consider to be a equivalent rectangular section*
- *it is consider that the crystallizer loose heat uniformly on each surface*
- *it is consider that at zero moment the temperature of steel mass is uniform. For the surface nodes it is correct to assume that at the casting moment it took place the formation of a thin solidified steel layer, and the loosed heat by this layer is transmitted instantaneously to the nodes from the interior surface of the crystallizer.*
- *the evolving of fusion latent heat it is produced in liquidus-solidus interval, direct proportional with the temperature*

CONCLUSION

Analyzing the graphical dependences from the performed researches, based on literature review data and from own experimental work it results the fallowing conclusions:

- *The results obtained by simulation with presented program being similar with practical data;*
- *In every diagram there are observed a temperature leap or a solidification speed leap after approximately 1min 7s min from the beginning of the casting, respectively immediately after the driving out from the*

crystallizer of the considered section, leap caused by the impossibility of elimination of a heat flux from the half-finished product interior;
- *It is observed a numerous crystallizing centers, uniform distributed;*
- *Also, it is observed an appreciate difference between the liquid steel temperature and the steel temperature from immediate proximity of micro-coolers;*
- *The indurations advances consisted standardized it a temperatures of first in of the minute after the administration of micro-coolers;*
- *After precinct a minute from the administration micro-coolers don't else notices significant differences what in looks the variation of the temperature of the in mass of steel;*
- *Through the addition of micro-coolers is obtained adjustment of the a temperature of the in of the crystallizer depending on the quality and the quantity of micro-coolers;*
- *Modifying a series of parameters (number of discretized points, dissipated heat in crystallizer and in secondary cooling, data of steel grade) it could be obtained more correct values, applicable to other steel grades.*

The number of nodes is established starting with the necessity of finding a solution for the following contradiction: the use of a high number of nodes increases the precision of the model (the error introduced by the hypothesis that the adjacent surface of every node has the same temperature as the node is decreases with the decrease of node area); on the other hand a high number of nodes lead to an increasing of processing time due to the increasing of nodes number and due to decreasing of time intervals between iterations imposed by stability conditions of the solutions.

The chosen time interval represent the time in which the unsteady heat transfer process is approximate with a steady process. From this reasons as well as the characteristics of the real process are far from that of a steady one, the iteration period should be smaller.

In order to realize a bi-dimensional mathematical modeling of a half-finished product it is considered a section of half-finished product-crystallizer assembly, which is divided using a discretisation network. The temperature of every node represents the mean temperature of node adjacent surface.

Continuous casting is used to solidify most of the 750 million tons of steel, 20 million tons of aluminum, and many tons of other alloys produced in the world every year. Most previous advances have been based on empirical knowledge gained from experimentation with the process.

As computer power increases, mathematical models are becoming increasingly powerful tools to gain additional quantitative insight.

Model applications include basic machine design calculations, identifying and quantifying the mechanisms of various types of defects, troubleshooting the origin of particular defects, and optimizing the various process conditions to increase productivity or minimize defects.

Continuous casting transforms molten metal into solid on a continuous basis and includes a variety of important commercial processes. These processes are the most efficient way to solidify large volumes of metal into simple shapes for subsequent processing. Continuous casting is one of the prominent methods of production of casts. Effective design and operation of continuous casting machines needs complete analysis of the continuous casting process.

The proposed algorithm can be used for the analysis of both stationary and moving solidification problems in which phase change occurs at a specific temperature.

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