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Computer Simulation of the Concepts of Filling of the Mould by the Thermal Aspects

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Abstract: In order to fill the cavity with a mould, entering metal must have heat required. The reduction in the temperature of the fluid passing by the system of release must be adapted in the treatment in order to make it possible the liquid to completely fill the interstices of the mould. The use of the fluidity of the molten metal like concept and variable of treatment to define the conditions of payment of metal was constant in the technical literature. Basic tests are employed to determine this parameter of thermal transfer in liquid metal operations, provided an occasion more particularly to define the behaviour of the molten metals in the moulds filled. These concepts presented by researchers, consider the loss of temperature of the molten metal while it crosses the system of release. The development of this model is based on a calculation of the loss of heat of the molten metal are equivalent to a tube with the models of release of these systems which accentuate by the unstable nature of the loss of heat reviewed. The computer simulation of this analysis was described by other researchers. The development of a model of unstable state is given where the system of release is simplified with an equivalent tunnel of flow by material of the mould. Local flows of heat are a function of time and the temperature of each metal increment can be given as soon as it enters the mould. The loss of heat in the system of release is the first stage by determining a first distribution of the temperature in the mould for the computer simulation of the concepts of solidification of the mould similar to those used to evaluate the loss of heat in the system of release can be employed to determine the initial temperature in the mould on the achievement of the filling of the mould. The incorporation of these concepts in the computer-aided design for moulds is necessary. What relates to the molten metal, Holman for example presented an analysis for the loss of the temperature by holding molten steel which is applicable to other metals.This review presented developments by quantitatively evaluating the losses of heat in the filling of the mould. It would prove that the quantitative aspects of the thermal transfer in the treatment of the molten metal were developed and checked in experiments. The current task is to integrate these results and to install them in a system computerized for the design of the mould of production. The fall of the temperature of the molten metal in the mould is taken into account. Several concepts and analyses having milked on the subject are presented. The use of the quantitative aspects in the evolution of the simulation computer-assisted for the design of the components is recommended.

Key words: Thermal aspect, mould, computer simulation, temperature

INTRODUCTION

To face international competition, the founders have a permanent preoccupation with a profit of productivity which is expressed by a will to gain in cost, time and quality. In this context, simulation became for a number of companies an essential tool. It indeed makes it possible to represent physical phenomena that real casting will not make it possible to highlight. It gives important indications on the phases of fillings and solidification, like on heat exchange moulds metal. At the stage of the preliminary draft, this information will be analyzed in order to optimize and to validate the design of the tools. In production, the software could be used in order to better include/understand the appearance of the defects and thus to cure it.

SIMULATION OF THE SOLIDIFICATION OF THE ALPAX ON COMPUTER

We presented the thermal parameters which intervene in a determining way during obtaining a casting. They vary from a casting with another and make notable modifications (Hentzel, 1996). These parameters are: - Geometry of the part, which we characterized by the thickness or the module of cooling:

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- Materials constituting the mould and playing the part of coolers.
- The temperature of run alloy.
- The physical properties thermo of materials used.

These last years, with the extension of the computers one is interested largely in the mathematical models illustrating at least correctly the phenomenon of study. Also one sought some mathematical models, simulating the solidification of certain metals, which seems, sufficiently interesting for the practice of foundry.

Formulation of the problem: The simulation of solidification, by using the computer and especially interesting, when it reproduces sufficiently reality, because it also enables us to calculate several alternatives without use of materials more often expensive at the time of the realization of the tests (Hlinka, 1991). It enables us to vary a factor, while maintaining constant the different ones, thus giving a better comparison and a facility of interpretation. Our research of study with for objectives:

- To seek the physical model of our part in solidification, containing knowledge a priori.
- To establish the mathematical model according to the found model, for the determination of the thermal parameters.
- To transform the mathematical model into numerical calculation.
- To write the problem thus posed in language of the calculating machine.
- To adjust the program thus found, with the experimental data.
- To analyze the found results.

Determination of the physical model of the part in solidification in the sand mould: We characterize our plane part by the thickness 2l which is low of 4 times in front of the length and the width. It is run in a mould infinite thickness (compared to that of the part).

In this case heat is evacuated in the mould especially by large the with dimensions side ones of the part. Our choice is justified besides by the practice where it is found that the totality of the castings can be regarded as infinite plates from the thermal point of view. During solidification, the temperature varies through the thickness of the part and according to time, because heat is continuously evacuated part towards the mould. The part is geometrically and thermically symmetrical and we can consider the problem unilaterally.

Thus the problem arising consists with the determination of the transitory field of temperature of the part of solidification. To return interesting the model and to approach reality we bring some simplifications which really take place during the process of the clothes industry of the part with alloy of study:

- Although our alloy presents a small interval of solidification, one can practically regard it as a eutectic solidifying at the constant temperature Tc.
- The initial temperature (or of cast) of the molten metal remains identical in any point of the part, just after the filling of the mould and especially higher than the temperature of solidification.
- The field of temperature does not remain uniform: The temperature of metal close to the interface metal-mould is always lower than that of the center.
- The solidification proceeds successively while progressing towards the center and the face of solidification can be considered flat (whereas actually it presents more or less regular asperities).
- According to the experiments which we carried out one can state these assumptions like valid. This admitted, we present the physical model of the solidification of our alloy in the sand mould at green on Fig. 1.

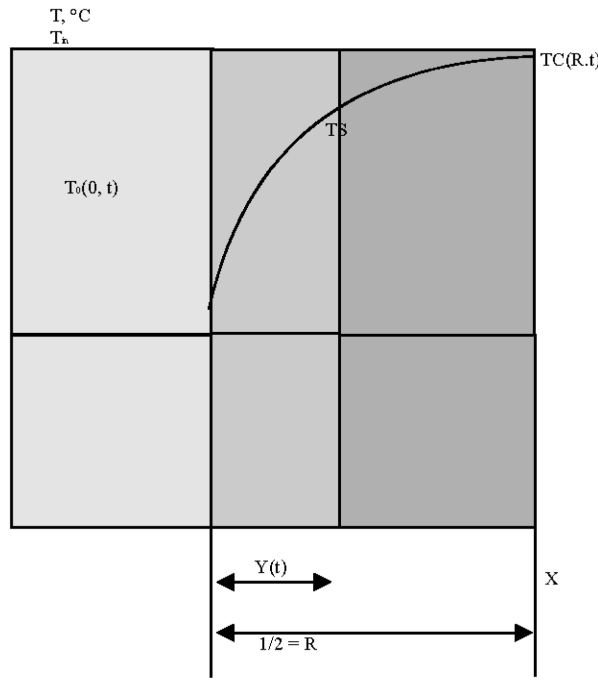

Fig. 1: Physical model of the solidification of the alpax in the sand moulds with green, TS: Temperature of solidification. TC: Temperature of the center of the part Tin initial temperature of metal or casting. Y(t): co-ordinates of the face of solidification, TI: Temperature of the interface moulds-metal

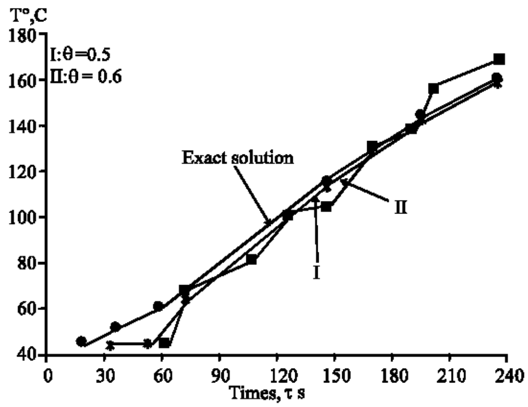

Fig. 2: Stability of the system of finite difference equations explicit [θ=as/ (1) ²]

The curve on the figure presents the distribution of the temperature at the moment t, through the half-thickness of the cast.

Figure 2 displays the results of the exact and numerical resolution of the problem of no stationary thermal conductivity for a plane wall divided into four intervals of time.

The influence exerted by Δx on the results of the resolution can be evaluated according to the data represented on Fig. 3. Curves I, II and III correspond to the solutions obtained by two, three and five nodes.

Determination of the mathematical model: For the description of the process starting from the physical model bench we can use the equation of the heat which, in its general form, binds the various variables which are time, space and the temperature. With this equation we can know the thermal mechanism in any point of the part and any moment. For our unidimensional case, the differential equation is written:

$$\frac{\partial T}{\partial t} = a \cdot \frac{\partial^2 T}{\partial X^2} + \frac{1}{c\rho} \cdot \frac{\partial w}{\partial t} \quad (1)$$

W is the heat of solidification or that of the phase shifts in a solid state. Actually these physical properties thermo are variable according to the temperature, the chemical composition, of the structure and even of the pressure. But under our condition one can regard them as constant bus:

- The interval of temperature that we study is weak.
- The determination of these properties in the liquid state, during solidification is not easy and gives approximate results.

Table 1: Thermal characteristics and beaches of variation of alloys used in our study

	Thermal characteristics		
Alloys	A, W/m/° C	ρ, Kg m^{-3}	C, J/Kg/° C
ALPAX	85	2210	935
			1265
		2990	935
			1265
	138	2210	1265
			935
		2990	1265
			935
Cast iron	25.5	5695	714
			966
		7705	714
			966
	34.5	5695	714
			966
		7705	714
			966

Table2: Initial conditions

	Alloys	
Parameters	Alpax	Iron cast
Temperature of casting	650 (°C)	1450 (°C)
Temperature of solidification	577 (°C)	1150 (°C.)
Dynamic viscosity	2,5. 10^{-5} (m² s^{-1})	6 .10^{-5}
Coefficient of compressibility	24.10^{-6}	24.10^{-6}
the step of space	0,01(mm)	0,01 (mm)
The step of time	0.05 (s)	(s)
Dimension of the part	(50 ; 10 ; 10) mm	(40 ; 10 ;10)mm

The physical characteristics thermo of alloys are given in Table 1.

To concretize the model, we must define the conditions starting from the physical model. We can write the following conditions:

Initial conditions and in extreme cases: To solve a problem of transfer of heat, it is at any moment to determine the field of temperature *T(x, y, z, t)* and that of the density of heat *Q (x, y, z, t)* for that, it is necessary to establish the equations of local heat balance and to write the boundary Conditions Space and Temporal (which we will note CLS and CLT).

It is obvious necessary to know the distribution of the initial temperature *T (x, y, z, 0)* to predict the evolution of the studied system.

To facilitate the exploitation of the methods of calculation we took the following initial conditions (Table 2).

METHODS OF RESOLUTION OF THE PROBLEMS OF THERMAL CONDUCTION

The most employed are: analytical method, numerical calculation and analogical methods. The analytical resolution must as well check the equation of

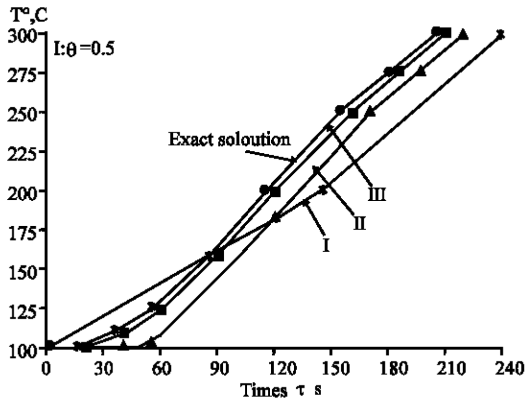

Fig. 3: Convergence of the numerical solutions according to the size of the step following the co-ordinate Δx

the conduction of heat as the boundary conditions (Zeng and Pehlke, 2003). It is generally obtained with the help of simplifying assumptions of which few problems in practice lend themselves to it. This method has the advantage of being easy applied when one has the parametric representation. The analogical method consists in studying the thermal process through a similar phenomenon, in the case of the thermal field it is similar to the electric field, the variable temperature is replaced by the electric potential. There exist much of problems of propagation of heat or the analytical solution cannot be obtained; and it is then less expensive or would take less time to obtain the experimental solutions in an analogical system and to make an interpretation according to the problem of the thermal flow. The numerical method, very much used with the development of the electronic computer electronic computers, is based on the solution of a whole of algebraic equations, or differential equation, by describing the equations corresponding to increase finished.

Numerical methods: In the determination of a stationary thermal field, most known is that known as of relieving, it consists in dividing the part into a number of finished elementary volumes. For the problems of conduction in no permanent mode the numerical method is different. Because one must determine starting from a known initial thermal distinction, a field whose variation is a function of time τ. The most known methods and which are largely used are the method the finite differences and the finite element method (variable field of temperature or not).

A finite element method: The principle consists in dividing the field of study into areas limited by triangles (or tetrahedron). One solves a system of algebraic equations then approaching the solution of the differential equation. It became very widespread in many problems of sciences applied. Its interest and its utility lie in the manner of circumventing the difficulties skilfully, especially daN the comprising parts of the complicated forms. If for the method the finite differences one transforms the differential equation into equation with increase finished, for that the finite element method which is also a method of approximation, one treats the solution of the differential equation.

The linear interpolation for example in a metal plate is written:

$$t = \left(1 - \frac{x}{1}\right).t_1 + \left(\frac{x}{1}\right).t_2 = f_1 t_1 + f_2 t_2$$

$$\text{Where } f_1 = \left(1 - \frac{x}{1}\right) \text{ and } f_2 = \left(\frac{x}{1}\right) \qquad (2)$$

where Are the temperatures with nodes 1 and 2 when one adds another center point one uses a higher degree, because one with three nodes having t_1,t_2,t_3

The function is here of the form:

$$t = a + bx + cx^2 \qquad (3)$$

If in x=0 $t_1 = t_{x=0}$ et $t_2 = t_{x=1/2}$ et t_3 $t_{x=1}$

One obtains

$$t = \left(1 - \frac{3x}{1} + \frac{2x^2}{1^2}\right)t_1 + \left(\frac{4x}{1} - \frac{4x^2}{1^2}\right).t_2 + \left(-\frac{x}{1} + \frac{2x^2}{1^2}\right).t_3 \qquad (4)$$

The differential equation is then:

$$\frac{d^2t}{dx^2} = \left(\frac{4}{1^2}\right)t_1 + \left(-\frac{8}{1^2}\right).t_2 + \left(\frac{4}{1^2}\right).t_3 = 0 \qquad (5)$$

This approach in this simple example makes it possible to obtain a good precision.

Methods the finite differences: As for the other methods one divides the thickness of the part in areas in the center of the which variable mode a content appears capacitive corresponding to increased internal energy during an interval of time.

The choice Δτ (or Δ x) limit however the initialization of the method as for the precision. and better will be the precision of results until approaching the analytical solution narrowly,

For values of á ranging between 0 and the 0.5 method leads to results more precise than those obtained by the explicit method.

$$\frac{\partial t}{\partial \tau} \approx \frac{\Delta t}{\Delta \tau} \approx \frac{t_0^{\tau+\Delta\tau} - t_0^{\tau}}{\Delta \tau} \approx \frac{t(x, \tau+\Delta\tau) - t(x,\tau)}{\Delta \tau} \quad (6)$$

$$\frac{\partial^2 t}{\partial x^2} \approx \frac{t(x+\Delta x) - 2t(x) + t(\Delta x)}{\Delta x^2} \quad (7)$$

$$\frac{\Delta t}{\Delta \tau} = a\frac{\Delta^2 t}{\Delta x^2} \quad (8)$$

$$\frac{\Delta^2 t}{\Delta x^2} = \frac{\Delta\left(\frac{\Delta t}{\Delta x}\right)}{\Delta x} = \frac{\frac{t_{x+1}^n}{\Delta x} - \frac{t_x^n - t_{x-1}^n}{\Delta x}}{\Delta x} \quad (9)$$

$$\frac{t_x^{n+1} - t_x^n}{\Delta \tau} = \frac{t_{x+1}^n - 2t_x^n + t_{x-1}^n}{\Delta x^2}.a \quad (10)$$

- The equation with the increases finished compared to that continuous comprises errors known as of truncation (negligible to a certain extent).
- The differential equation can then be replaced by a linear equation:

$$\frac{t_x^{n+1} - t_x^n}{\Delta \tau} = \frac{\lambda}{c\rho.\Delta x^2}(t_{x+1} - 2t_x + t_{x-1})^n \quad (11)$$

$$\left(t_x^{n+1} - t_n\right)\frac{c\rho\Delta x^2}{\Delta \tau} = \lambda.\left(t^n{}_{x+1} - 2t^n{}_x + t^n{}_{x-1}\right) \quad (12)$$

$$\left(t_x^{n+1} - t_n\right)\frac{c\rho\Delta x}{\Delta \tau} = \left(\frac{t^n{}_{x+1} - 2t^n{}_x + t^n{}_{x-1}}{\Delta x}\right) \quad (13)$$

$$\left(t_x^{n+1} - t_n\right)\frac{c\rho}{\lambda}.\frac{\Delta x}{\Delta \tau}.\Delta x = .\left(t_{x+1} - 2t_x + t_{x-1}\right)^n \quad (14)$$

$$\left(t_x^{n+1} - t_n\right)\frac{1}{a}.\frac{(\Delta x)^2}{\Delta \tau} = .\left(t_{x+1} - 2t_x + t_{x-1}\right)^n \quad (15)$$

$$t_x^{n+1} = \frac{a\Delta\tau}{\Delta x^2}.\left(t_{x+1} - 2t_x + t_{x-1}\right)^n + t_x^n \quad (16)$$

$$t_x^{n+1} = f_0.t_{x-1}^n - 2t_x^n f_0 + f_0.t_{x+1}^n + t_x^n \quad (17)$$

$$t_x^{n+1} = f_0\left(t_{x-1}^n + t_{x+1}^n\right) + t_x^n\left(1 - 2f_0\right) \quad (18)$$

Requiring the resolution with each τ a system of algebraic equation with the use of a calculator.

Finite difference equations explicit: For the resolution by the method the finite differences of the one-dimensional equation of thermal conductivity.

$$\partial T/\partial \tau = a\partial^2 T/\partial x^2 \quad (19)$$

The derivative which appears in it is approximated by the derivative to the finished differences.

$$\partial T/\partial \tau \approx \left(T_i^{k+1} - T_i^k\right)/\Delta\tau \qquad \partial T/\partial x \approx \left(T_{i+1}^k - T_i^k\right)/\Delta x$$

$$\partial T/\partial x \approx \left(T_i^k - T_{i-1}^k\right)/\Delta x$$

$$\frac{\partial^2 T}{\partial x^2} \approx \frac{1}{\Delta x}\left(\frac{T_{i+1}^k - T_i^k}{\Delta x} - \frac{T_i^k - T_{i-1}^k}{\Delta x}\right) = \frac{T_{i+1}^k - 2T_i^k + T_{i-1}^k}{(\Delta x)^2}$$

The analogue with the finished differences is then form

$$\left(T_i^{k+1} - T_i^k\right)/\Delta\tau = a\left(T_{i+1}^k - 2T_i^k + T_{i-1}^k\right)/(\Delta x)^2 \quad (20)$$

The values of the derivative partial of the temperature T compared to time and the temperature (compared to co-ordinate *x*) are replaced in (20) by their approximate values and the corresponding differences, by the finished increases. In particular, Δx and are small increases in the independent variables *x* and Δx is a step following the co-ordinate; $\Delta\tau$ a step following time).

To solve this equation, the temperature is calculated only for isolated points I = 1, 2,3,..., *n*, resting on the axis of *x*; it is supposed whereas at every moment, the distribution of the temperature in the interval between the close points is linear, at the time of the resolution of the problems multidimensional, these points are usually called nodes of the space lattice. In the simplest case, the intervals between these points are equal between them and with Δx the expression (11) must be considered as a system of algebraic equations of which number N is equal to that of the unknown temperatures. Indices k and k+1 define the moment to which the value of the temperature corresponds is the value of the temperature at a certain moment τ; $T^{k=1}$the value of the temperature at moment $\tau + \Delta\tau$ each finite difference equation contains only one unknown factor. This temperature appears in node I after the flow of the small interval of time .

It is supposed whereas the initial temperature in each node is T^k_i. The approximation with the differences which has been just described is not the only possibility.

The Eq. 20 is built according to the diagram with the finished differences clarifies traditional and solves

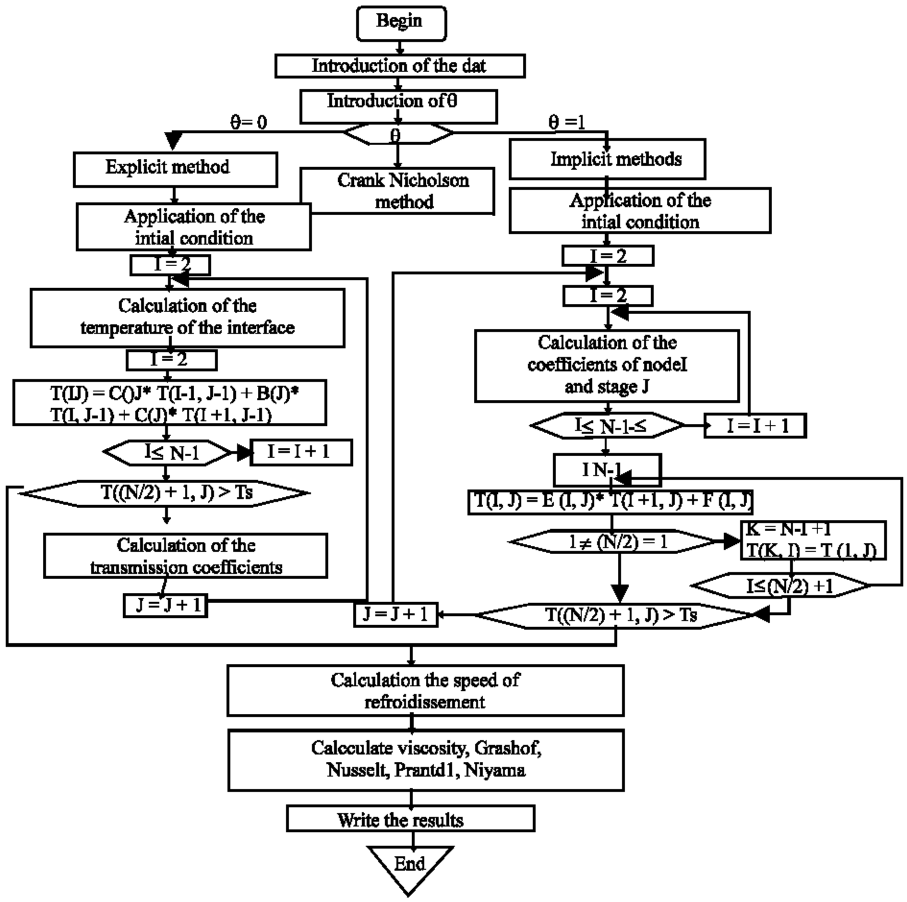

Fig. 4: Flow chart total of the program

without sorrow in an explicit form compared to the unknown function. For the calculation of the unknown temperatures $T_i^{k=1}$, the system made up of *n* equations algebraic of the type (20) is solved successively for each step (sections) in the interval of time of calculation.

When one carries out the first step in time and the system (18) is solved for the first time, the values of the initial temperature are drawn from the initial conditions. (According to the initial conditions, the distribution of the temperatures at moment $\tau = 0$ must be given.) In the successive resolutions, the values of T^k_i are taken starting from the previous section of time.

Stability of the system of finite difference equations explicit: For the resolution of a system of finite difference equation, the correct choice of and Δx are decisive (Holman, 1981). By retaining the diagrams with the explicit finished differences, the size of the step in acceptable time is limited and for the interior nodes it depends on the step chosen according to the co-ordinate and the diffusivity of material $a = \lambda/c\rho$.

Figure 3 displays the results of the exact and numerical resolution of the problem of nonstationary thermal conductivity for a plane wall divided into four intervals of time.

The comparison shows that calculations with $a\Delta\tau/(\Delta x)^2 = 1/2$ provide perfectly satisfactory results, whereas with $a\Delta\tau/(\Delta x)^2 > 1/2$ the phenomenon of instability appears. It is not related to the errors of district, but results from the properties of the system of finite difference equations itself. By solving the Eq. (20) in an explicit form compared to the function inconnue T_i^{k+1}, its obtains:

$$T_i^{k+1} = AT_{i+1}^k + BT_i^k + CT_{i-1}^k \qquad (21)$$

Where $A = C = a\Delta\tau / (\Delta x)^2$; $B = 1 - a\Delta\tau / (\Delta x)^2$. Moreover $A + B + C = 1$.

The advantage of the finite difference method implicit lies in the choice of the increment and space without particular constraints.

The unquestionable advantage of this method is that each equation contains only one unknown factor which is the value of the temperature for $\tau+\Delta\tau$ whereas that σ is supposed to be known or determined. Thus to avoid instabilities in the calculation of the field of temperature M must be equal to or higher than two for this equation. The difficulty compared to the explicit method is the resolution of the system of algebraic equations obtained, especially when the number of nodes is important. The use of a calculator becomes necessary.

According to the flow chart (Fig. 4) one worked out a calculation programme by the method the finite differences. This program deals with two alternatives of this method which are the implicit and explicit method. Our program describes the stages of calculations of the thermal field by the exploitation of the initial conditions and the function of the temperature of interface, as well as under calculation programmes the speed of cooling, viscosity and the various adimensional numbers.

CONCLUSION

According to the results which one obtained by the program and their agreements with work of several authors, one can confirm the effectiveness of simulation by the mathematical methods with great confidence interval. Thus one can conclude that the exactitude of the results of simulations makes especially widen the field of use of the software based on data-processing programs whenever one must vary several parameters severely applicable in the laboratories of the various fields. Local flows of heat are a function of time and the temperature of each metal increment can be given as soon as it enters the mould. The loss of heat in the system of release is the first stage by determining a first distribution of the temperature in the mould for the computer simulation of the concepts of solidification of the mould similar to those used to evaluate the loss of heat whose system of release is employed to determine the initial temperature in the mould on the achievement of its filling. The incorporation of these concepts in the computer-aided design for moulds is necessary. Quantitative aspects of the thermal transfer in the treatment of the molten metal were developed and checked. Several concepts and analyses having milked on the subject are presented. The simulation assisted by computer for the design of the components is recommended.

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