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Simulation of the Filling and Solidification in Foundry of Precision

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Abstract: The simulation of the filling and the solidification of thefoundingpartsis an essential stage to optimize the design of the moulds. The following one is even more in order to be able to predict in same time the level of the defects in the parts. The research concerns the study of the filling of the mould in order to determine its influence on the solidification of cast alloy. We established a calculation programme which makes it possible to simulate the filling of our mould starting from the flow of the liquid at exit of the crucible.The simulations results required the adaptation ofmeshing of the considered problem. The results of these simulations made it possible to define the quantity of the liquid present in each element at every moment at various speeds of casting.Our study includes the determination of the influence of the various considered parameterson the resulting thermal field. In our particular mould, it appeared that the speed of casting is the parameter which controls the phenomenon facing the temperatures of pre-heating of the mould the and alloy melt.

Key words: Foundry, filling, solidification, simulation, part, parameterson

INTRODUCTION

The lost wax foundry is a process used currently to produce complexparts with high value added including inter alia the paddles of turbines. These parts, increasingly fine with the development in the technologies and in alloys, are subjected to increasing stresses.

Therefore, we are looking to tighten to the top the range of the characteristics while controlling, in a very strict way, the porosity of the aubes.They are thus, more difficult to obtain and it becomes necessary to refine knowledge on the solidification of the parts produced in foundry of précision. Many authors already announced the use of the computer to determine the parameters of solidification in the case of continuous casting or in ingots (Albouy, 1976; Weinber, 1977). The sand casting (Jeyrajan and Pehlek, 1975) orin die cast (Bakman *et al*., 1977) are less studied and it is generally the influence of simple geometrical parameters which is taken into account (Sciama, 1971). Such calculations were carried out systematically during theadjustment withunidirectional solidification of eutectic superalloys (Giamei and Erickson, 1976). It seemed to us interesting to apply such methods of automatic calculation to investment moulding.

In foundry of precision, the solidification of a part depends on the existing thermal field in the mould and inpoured metal (Braun, 1990; Mantaux *et al*., 2000). The time of filling is very short, of about a second. The temperature of metalextended very quicklyjust after itleaves the crucible. It is thus, difficult to just know the thermal field after casting. This is however, necessary when one wishes to study the solidification of the part.

In order to solve this problem, we study the flow of the liquid in a ceramics mould made up of four vertical bars fed in sourcefrom point of view of the foundry of precision, it matters that the filling is carried out quickly and in a homogeneous way. Indeed, a too long time of filling causes a great cooling of the métal.In the thin parts, this generates a premature solidification, therefore defects of badly-arrivalin spite ofthe overheating of metal and the stoving of the mould (Linxe, 1999; Ocando, 1984).

The study of the mode's flow of liquid alloy in theshell must make it possible quantitatively to evaluate heat exchange during the filling of the mould. We consider also the thermal field of the metal of which we can then simulate solidification.

The thermal transfers in foundry utilize a great number of parameters. Geometry of the part and its packing; external cooling; the temperature of casting metal; the temperature of stoving of the mould; specific

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heats and thermal conductivities of materials; the way in which the latent heat of metal is released on the interval of solidification.

The experiments of filling which we carried out make it possible to know the mode's filling of the mould already outlined. we propose to use these results's flow of liquid in the mould in order to consider the thermal field of the system right after the filling of the mould.

The thermal program's transfer uses the finite element method (Waite and Samonds, 1993) which requires ameshingit meansa geometrical cutting of the part in finite elements in which it is necessary to determine volume, side surfaces and distances from the center of gravity on its various surfaces. Because of the symmetry of the mould, our study considers a half test specimen.

We propose ameshing whichinvolve one hundred and nine elementsin which 26 metal, forty in the shell, forty one in packing out of sand and two in the wool minéral. Thismeshingis conceived in order to improve the precision of calculation in the direction of the flow of the liquid during the filling and in the elements closest to the metal elements.

Experimental part: The experimental device used ismade upof the following elements: asell out of ceramics bored at various places noted 1-15 on the Fig. 1.The conducting wire of platinum are placed in these holes. They are used as contact toclose electric circuit at the time when the liquid reaches each level of the mould. For the acquisition of the results, we used an oscillograph multichannel ABEM ultralette 5656. This deviceis equip-ped with 6 minigalvanometers provided with a mirror.
We chose 5 groups of sensors:

A(15, 9, 5); B (14, 3, 12); D (1, 10, 6);
E (2, 4, 13); F (8, 11, 7).

When the crucible containing initially a liquid is tited, this one touches initially the sensor (0) placed at the edge of the crucible and then it falls into the cup and wets the common contact (C) connected to the positive pole of the sources of courant. It continuous its way in the central channel placed under the cup closing successively the contacts 15, 14 and 1. It castthen in the 4 channels of distribution corresponding to the four bars laid out in cross around the cup supposing that there does not exist preferably between the four bars, the order in which the sensors must be reached by the liquid is as follows:2, 8, 9, 3, 10, 4, 11, 5, 12, 6, 13 and 7.For this reason, we decided to connect on the same galvanometer these about equidistant sensors.

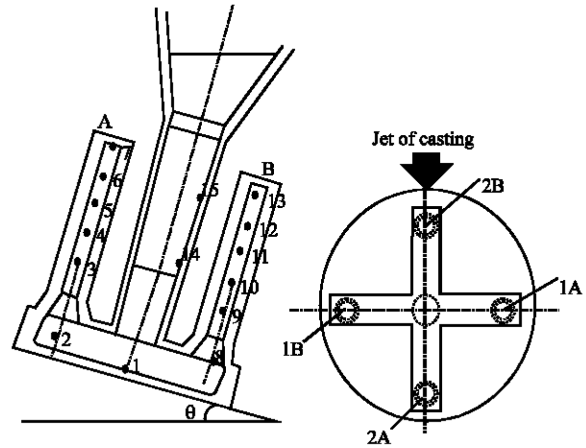

Fig. 1: Diagram of the mould indicating the position of the instrumented test-tube

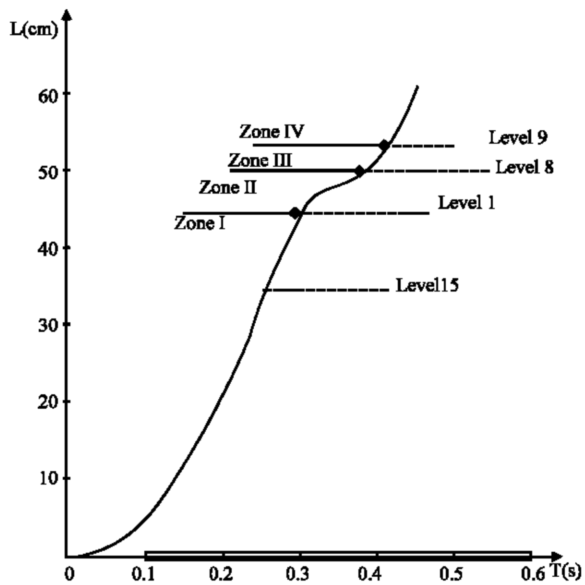

Fig. 2: Progression of the liquid face starting from its exit of the crucible for θ =15°

Casting is carried out in a vacuum pouring furnace.The liquid iscast by tilting of the crucible asfast as possible. Each established contact is detected by our oscillograph with fast ultra answer giving a definition of times higher than the hundredth of seconde. This makes it possible to determine with precision the moment of establishment of the contacts and to deduce the flow mode of the liquid in the mould, taking into account the study speed of the studied phenomenon.The Fig. 2 represents the progression of the front liquid as of its exit of the crucible, according to time T, in our tests with 15° of slope.

Here, we observe the existence of 4 definite zones: Zone I described the movement of the front liquid from its exit of the crucible until its arrival on level 1; the zone II which goes from level 1 on level 8; zone III gives the passage of the front liquid to level 8 and 9 and zone IV corresponds to therange of level 9 until the final filling of the cylindrical test specimen.

Ourmeshing is conceived in order to improve the precision of calculation in the direction of the flow of the liquid during the filling and in the elements closer to the metal elements (taking into account the speed of the studied phenomenon). The sell is cut out in ten altitudes on the level of the test specimen. An identical cutting is used for the sand which borders the shell. The mould is thus divided into one hundred and nine elements. We consider thatthere is aperfect contact between different surroudings.For more geometrical data which define for each element its nature, its volume and its initial temperature, for each conduction or radiation its surface of contact and the distance between the center of gravity and this surface, it is advisable to define the thermal properties of used materials.

RESULTS AND DISCUSSION

The thermal transfers in foundry utilize a great number of parameters. Geometry of the part and its packing, external cooling and the temperature ofcasting metal. The specific heats and thermal conductivities of materials. The way in which the latent heat of metal is released on the interval of solidification.

The experiments of filling which we carried out make it possible to know the mode of filling of the mould already outlined. We propose to use these results of flow's liquid in the mould in order to consider the thermal field of the system right after the filling of the mould.

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The cylindrical test specimen was cut out in twenty numbered elements from 1 to 20 in the following order. Theupperof the cup is supposed to be empty of metal. The shell is cut out in ten altitudes on the level of the test specimen.The thermal transfers in foundry utilize many

Table 1: Composition of alloy AM1

Ni	Cr%	Co%	Mo%	Ta%	W%	Ti%	Ai%	c%
Base	7.5	6.5	2	8	5.5	1.2	5.3	≤0.01

parameters of which physical characteristics such heat capacities, conductivity, etc…., of each component of the moule.The chemical composition of selected alloy is given by the Table 1.

In the carried out tests , we studied the influence of the angle of slopeof theshell and the relative position of the instrumented test specimen. For 15° of slope, we obtain a homogeneous filling what confirms the results obtained by Ocando (1984). Considering our particular system and looking at the various zones, we can deduce that the rate of flow increasesbecause ofthe force of gravitation while the liquid go down. Application of the totaltake stock of mass, momentum and energy of the system, enables us to model our phenomenon. Our calculation programme of course takes into account the various variations rate of flow of the liquid, had mainly with the geometrical singularities of the mould.The flow charts are used to simulate the filling of the mould.We note according to the results set up in Fig. 3-6 that there is a weak variation on the temperatures of the various elements on the level of the test specimen as well as a fall of temperature during the filling compared to the temperature of casting.This shows the influence of the filling on the thermal field of the mould to be used during the simulation of the solidification. The casting parameters such as, the speed of casting, the temperature of stoving and overheating have a clear influence on solidification.

Interpretation of Fig. 3-6: Figure 3 shows in a quantitative way, the influence the speed to which one casts the molten metal in the mould on the temperature of the various metal elements once the filling effected. It exists an opposite relation between the speed of filling and the fall of temperature in the metal elements during the filling.

In Fig. 4 we note that the temperature of the mould has little influence on the fall of temperature when the speed of filling is high. On the other hand, if the filling is carried out more slowly, the molten metal undergoes a fall of temperature which goes until 14°C for a difference in temperature of stoving of 68°C. This is related to the speed of extraction of heat by the mould in contact with the liquid during a time more prolonged.

Figure 5 shows the influence of overheating was studied by simulations of the temperatures of run of 1450 and 1420°C, without modifying the stoving of the mould which is maintained with 920°C. This reduction in the

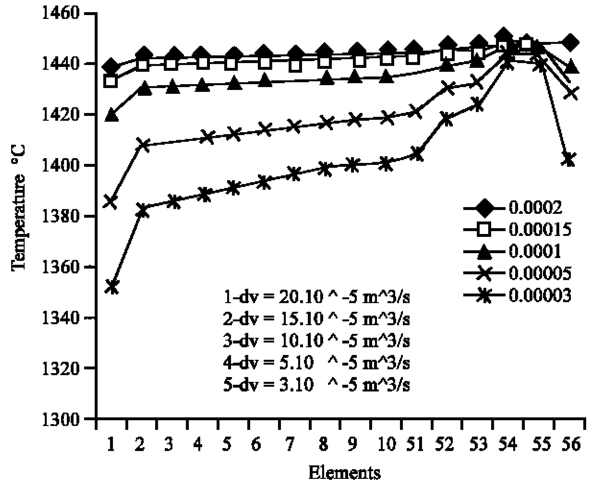

Fig. 3: Temperatures of the metal elements obtained by simulation filling with various flows (dv)

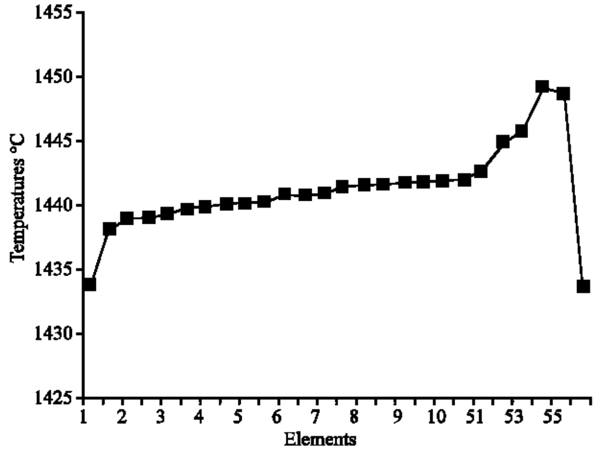

Fig. 6: Temperatures of the metal elements after total filling

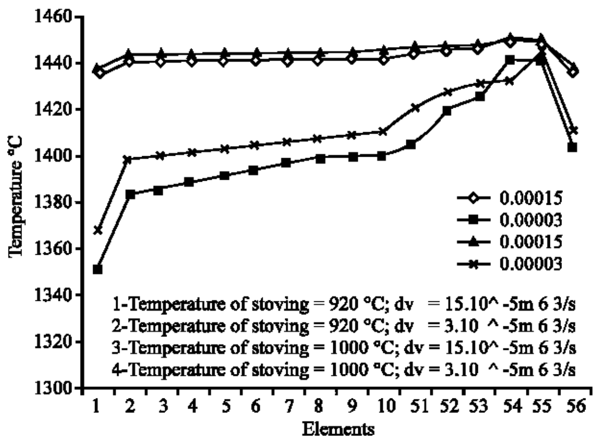

Fig. 4: Influence temperatures of stoving of the mould at various speeds of filling

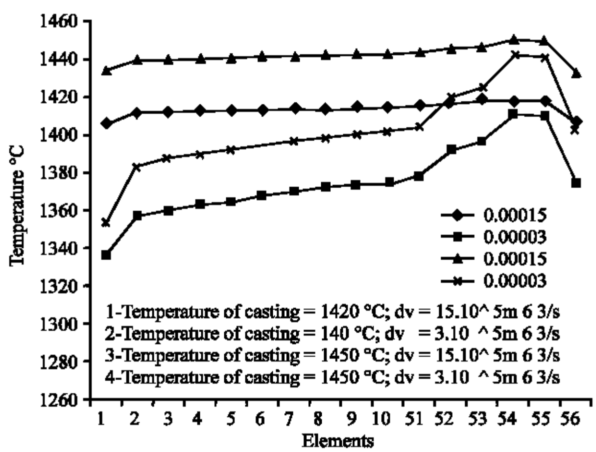

Fig. 5: Influence temperatures of the flow at speeds of filling

temperature of cast produces a weak reduction in the thermal transfers as the results of simulations show it. Indeed, we observe on the figure that the difference in temperature of 30°C is not maintained in the metal elements after the filling, especially when the speed of casting is feeble. These simulations at various temperatures of casting again show the importance of the kinetics of the filling on the change of the temperatures of the metal elements.

Figure 6 We note that there exists in general, a weak variation on the temperatures of the various elements on the level of the test-tube as well as a fall of temperature during the filling which goes until 16°C compared to the temperature of casting. That shows the influence of the filling on the thermal field of the mould to be used during the simulation of solidification.

CONCLUSION

The simulation of the thermal transfers during the filling of a mould was concluded while adding to an existing computer code, a progamme of simulation of flow of the liquid in this mould.This simulation requires more over, to know the liquid flows, estimated by another calculation programme starting from the experimental observation of the front liquid in the mould during its filling.This simulation makes it possible to compare the respective influence of the various parameters which characterize a casting: The casting speed of liquidmetal in the mouldseems to be the more sensitive factor. In fact, we regarded only as variable the initial flow of the liquid. In reality,in addition to this parameter, it is necessary to take into account the precise positioning of the mould compared to the runner, which can involve a deceleration of the liquid in contact with the central channel.The temperature of stoving also acts on the variation in the temperature of the metal elements throughout therange of the liquid in the mould, but its action is less strong than that the casting speed. The casting temperatureliquidmetal plays uniformly on these températures.The over heating of the liquid is thus necessary to avoid the formation of a partial solid, during the filling, but it acts a little on the heat gradients in metal which control there after the solidification of this one in the mould. The comparison of the simulation of the solidification of real parts with recordings of temperatures, shows that reality is rather well reproduced. A calculation of pressure losses undergone by theliquid metal during cooling can then be carried out since all the essential data are obtained at the time of the simulation. This calculation makes it possible to evaluate the influence on porosity, of various parameters of foundry: Temperatures of stoving and casting, geometry of packing as well as parameters characterizing alloy.The simulation of the solidification of castings of precision can thus help the development of a casting by giving the direction of the influence of unquestionable parameter on porosity.

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