PREDICTION OF SHRINKAGE CAVITIES IN ALUMINUM-SILICON SAND CASTING

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ABSTRACT

This work aims to predict the shrinkage cavities of Al-12%Si castings by using the solidification simulation model. The locations, volumes, and extensions of these cavities were predicted by applying new method. This method consists a computation process of the nodes volume variation through the variation of their densities with time, then subtracting the equivalent of these variations from the hot spot nodes. Additionally, an experimental study was performed to check the competency of the prediction method and the model through study the effect of the pouring temperature and the castings geometry on the cavities volume and locations in these castings. It was found that, the present method and model brought out a good prediction of the cavities volume and locations. Also, they showed a good responding to the variations of the castings shape and pouring temperature.

الخلاصة

يهدف البحث الى تخمين فجوات الانكماش في مسبوكات من Al-12%Si بأستخدام عملية محاكات التجمد. لقد تم تحديد مواقع وحجوم وامتداد هذه الفجوات بطريقة جديدة. تتضمن هذه الطريقة عملية حساب تغيرات حجم العقد عبر تغير كثافتها مع الزمن ثم طرح مكافىء هذا التغير من العقد من المراكز الساخنة. اضافة لذلك، اجريت دراسة مختبرية لغرض التأكد من كفاءة طريقة التخمين والموديل عبر دراسة تأثير درجة حرارة الصب وهندسية المسبوكة على حجوم ومواقع الفجوات في هذه المسبوكات. و وجد ان الطريقة الحالية والموديل قد اظهرا تخمينا جيدا لحجوم ومواقع الفجوات. وايضا فقد اظهرا استجابة جيدة لتغيرات شكل المسبوكات ودرجة حرارة الصب.

KEYWARDS: Casting, Simulation, Modeling, Shrinkage, Cavities, and Porosities

INTRODUCTION

Shrinkage phenomenon is the main source of most casting defects. The reason of solidification shrinkage is the fact that the density of the solid state is higher than that of liquid state. Many research concentrated towards the shrinkage defect prediction by casting modeling. The first published reference to the use of the digital computer in a foundry related application is that of Fursund **[1] in Denmark at (1962). Heat-transfer models, do not in themselves model the formation of porosity, but the physical interpretation of data leads to get indicators of porosity [2, 3].** Daws **[4] built up a two dimensional mathematical**

model in metal region and a one dimensional model in mold region. The model was used to check the validity of the freezing isotherm and location of the zone of cavity formation in casting. A measurement of the porosity of aluminum cast alloys using fractal analysis was carried out by huang **and** Lu **[5]. This method uses two dimensional parameters (roughness D and sphericity B). A porosity distribution map can be constructed to describe the shape and distribution of the pores in the microstructure.** Othman **[6] built up a three dimensional mathematical model to estimate the shrinkage defects. From the results of calculating the solidification time, the appearance of a closed loop in the solidification time contours was the indication for the prediction of the shrinkage defects in castings.**

The present work aims to evaluate a new method of shrinkage cavities prediction which can be employed in the casting simulation model. Also, it aims to check the responding of this model to the variations of pouring temperature, casting shape, and their effects on the shrinkage cavities volume and locations.

MATHEMATICAL MODEL AND NUMERICAL SOLUTION

The Fourier heat conduction equation is used as a mathematical model for the casting system components, which is:

$$\rho C_p\left(\frac{\partial T}{\partial \tau}\right) = K\left[\left(\frac{\partial^2 T}{\partial x^2}\right)+\left(\frac{\partial^2 T}{\partial y^2}\right)+\left(\frac{\partial^2 T}{\partial z^2}\right)\right]+q^* \qquad \textbf{(1)}$$

where the ρ is the density, C_p is the specific heat of casting, τ is a time step, and the term $\rho C_p(\partial T/\partial \tau)$ is the transient term. In the right side the three terms represent the heat conduction in three-direction with thermal conductivity K. A source term q* is an internal heat generation for solidification under equilibrium condition. This term can be described as [7]:

$$\dot{q} = \rho L\frac{\partial f_s}{\partial \tau} = \rho L\frac{df_s}{dT}\frac{dT}{d\tau} \qquad \textbf{(2)}$$

Where L denotes latent heat distributed over the solidification range, so it is a function of the solid fraction f_s.

After discretization of the whole domain and using the forward difference for the time derivative and the central difference for the spatial second derivative, the approximation resulting in:

$$T_{i,j,k}^{t+1} = T_{i,j,k}^{t} + \frac{K\Delta\tau}{\rho C_p}\left[\frac{T_{i-1,j,k}^{t} - 2T_{i,j,k}^{t} + T_{i+1,j,k}^{t}}{\Delta x^2} + \frac{T_{i,j-1,k}^{t} - 2T_{i,j,k}^{t} + T_{i,j+1,k}^{t}}{\Delta y^2} + \frac{T_{i,j,k-1}^{t} - 2T_{i,j,k}^{t} + T_{i,j,k+1}^{t}}{\Delta z^2}\right] \qquad (3)$$

THE PRESENT METHOD OF SHRINKAGE CAVITIES PERDICTION

1-Determination the temperature of each cell at each time step.

2-Comparing the temperature of the casting nodes with the solidus temperature, if the node temperature is less than or equal to the solidification temperature, the fraction of solid in this node will set to 1.

3-At each time step, the isolated liquid regions R_l ($T_{cell} > T_{liquidus}$) are identified in the casting and the flag of node will be 3.

4-At (t+1) time step, the volumetric change in each node (ΔV) is computed from the change in density (ρ) as following:

$$\Delta V = V^t - V^{t+1} = V^t * \beta \qquad (4)$$

where (V^t) is the initial volume (beginning of time step) of specific node, (V^{t+1}) is the next volume (end of time step) of the same node, and (β) is the shrinkage ratio. So;

$$\beta = 1 - \frac{V^{t+1}}{V^t} \qquad (5)$$

from the mass conservation principle, the relation will be:

$$\beta = 1 - \frac{\rho^t}{\rho^{t+1}} \qquad (6)$$

finally the volume change becomes:

$$\Delta V = V^t (1 - \frac{\rho^t}{\rho^{t+1}}) \qquad (7)$$

The density in the mushy region is calculated from its values at solid and liquid states and the value of solid fraction (f_s) at a specified temperature (T) is calculated using the mixture rule which it is:

$$\rho = f_s \rho_{sol} + (1 - f_s)\rho_{liq} \qquad (8)$$

while the solid fraction at this temperature is computed from the following equation [8]:

$$fs = 1 - \left(\frac{T - T_s}{T_l - T_s} \right) \qquad (9)$$

where (T_s) and (T_l) are the solidus and liquidus temperatures.

5-The total volume change of the region at the time t+1 is:

$$\Delta V_l^{t+1} = \sum_{(i,j,k)\in R_l} \Delta V_{i,j,k}^{t+1} \qquad (10)$$

6-The total volume change of the region at the time t+1 is divided by the volume of node to obtain the number of nodes that must be removed.

7-The top layer of the remained liquid and the maximum temperature node of the top layer are defined.

8-The total available liquid volume of the top layer V_{lk} is estimated in the region R_l.

9-The total volume contraction is subtracted from the top layer of the maximum node $V_{lk,\,max}$ within the top of liquid region.

10-The first shrinkage cavity will appear at the top of the highest temperature part of casting. For an isolated liquid region, this procedure will produce a shrinkage cavity within the casting in the same manner as above from the maximum nodes temperature.

11-After all cells have been considered; the new temperature distribution for both metal and mold is calculated and the above procedure for all the cells including metal will be repeated.

12-The procedure is repeated until all the liquid becomes solid.

The basic structure of the program which was built up by using FORTRAN 90 language which is illustrated in figure (1).

EXPERIMENTAL PROCEDURE

To ensure the competency of the present method and the computer model in simulation and cavity prediction, a real casting of six different shapes and dimensions of Al-12%Si samples (figure 2) were performed. The melting process is done in a gas furnace, and then the molten metal degassed with C_2Cl_6 and poured in sand molds. These samples were prepared to study the effect of the sample shape and the pouring temperature on location, extension and distribution of the shrinkage cavities, and to inspect the model response value in prediction these variations.

RESULTS AND DISCUSSION

Figures (3 to 8) belongs to the casting samples (1 to 6) respectively. Every figure consists of real section (part a) and simulated section (part b) of these castings. Figure (3) shows good agreement between the simulated and experimental estimations in both volume and location of the primary pipe and the internal cavity.

Another good agreement is shown in figure (4) of sample (2), whereas the rectangular casting is free of defects which reflects the affectivity of feeder in compensation the molten alloy to the hot center. On the other hand, the shrinkage concentrated as deep piping in feeder with simple difference in the nature (distribution, shape) which can be attributed to the low overheating temperature before pouring.

In figure (5) the model of sample (3) succeeded in prediction the shrinkage defects locations and volume in both the feeder and casting center with a difference in the nature, so in real they appear as dispersed small cavities, while they appear as big cavities in simulation. This difference can be attributed to the low overheating temperature of the melt before pouring and to the dendritic solidification behavior which was not taken into consideration through model construction.

Figures (4) and (5) develop the ability of the model to comply with the change of gate thickness in feeding success to the shrinkage volume in sample(2), and feeding hindering to the shrinkage volume in sample(3).

Figures (6) and (7) which belong to samples (4) and (5) were cast from the thin side without feeders. They show the success of the model in prediction of shrinkage cavities concentrated at the thick side of the casting which plays as a feeder to the thin side.

Sample (6) which was cast with feeder, develops an additional success of the model in anticipation of the shrinkage defects despite they appear as big cavity in the casting center in contrast with real so they present as dispersed fine cavities (figure 8). This difference was already explained.

The Effect of The Pouring Temperature

Sample (1) was used to inspect the model responding toward the melt temperature change through study the effect of pouring temperature on the shrinkage cavities volume and location. A casting process was carried out at three different pouring temperatures (590, 610, and 630 °C). Figures (9, 10 and 11) illustrate the real section (part a) and simulated section (part b) of the three above cases.

Overall the simulated and experimental results show good qualitative agreement, so the model has an acceptable reacting to the pouring temperature change. Additionally, the pouring temperature has no effect on the location of shrinkage cavities.

Figure (12) presents the variation of simulated shrinkage cavities volume with the pouring temperature change. It increases with increasing the pouring temperature. However, the program deals with liquid and solidification contractions clearly by considering the density variations with temperature.

It can be noticed that beyond 610°C, there is a dramatically increase in volumetric shrinkage. This can be due to that, the raising of pouring temperature promoted the appearance of the shrinkage cavities instead of microporosities, because the model was designed to detect the cavities only.

Figure (13) shows the simulated relationships between volumetric shrinkage and solidification time for the three different pouring temperatures of sample (1). It seems that volume shrinkage increases rapidly until time of (20) second, because the effect of the mold walls which cause a high cooling rate at the beginning of solidification, so it makes a lot of nodes change from liquid to solid state rapidly, while after that, the number of nodes that changes from liquid to solid state decrease due to the latent heat evolution. Also the metal nodes that far from the mold wall will have a low cooling rate, so it needs long solidification time, thus the volume shrinkage increases slowly till all the nodes become solid.

CONCLUSIONS

1- The simulation model using the present method of nodes volume computation developed a good prediction of shrinkage cavities volume and location in different Al-12%Si casting shapes.
2- The model showed a good responding to the castings shape and pouring temperature variations.
3- The simulated shrinkage cavities volume increased with increasing pouring temperature.
4- During the solidification process, the simulated shrinkage cavities volume started with rapidly increasing, then it gradually slowed.

REFERENCES

1. K. Fursund, Das Eindringen von Stahl in Formsand. (quoted) Einfluss Der Oberflachenreaktion under Temperature, Giesserei Tech. Wiss. Beih., Vol 14, pp. 51-61,1962.
2. E. Niyama, T. Uchida, M. Morikawa, S. Saito, "A Method of Shrinkage Predicting and Its Application to Steel Casting Practice", 49th, International Foundry Congress, pp. 1-14, 1982.
3. E. Niyama, K. Anzai, and T. Uchida, “Application of a simplified solidification simulator to casting practice”, Beijing International Foundry Conference (1986).
4. K. M. Daws, "Computer Simulation for A Casting Mould Design", Ph.D. Thesis,
5. Y. J. Huang, S. Z. Lu, "A Measurement of the Porosity in Aluminum Cast Alloys Using Fractal Analysis", Michigan Technological University, pp. 1-5, 2000.
6. F. M. Othman," Numerical and Experimental Estimation of Shrinkage Cavities during Metal Casting", Ph.D. Thesis, Department of mechanical engineering, university of Baghdad, Iraq, 2006.
7. Imafuku and K. Chijiwa, "A Mathematical model for shrinkage cavity prediction in steel casting", AFS Transactions, 10, pp. 527-540, 1983.
8. D. Poirier and M. Salcudean, “On numerical methods used in mathematical modeling of phase change in liquid metals” Transactions of Heat Transfer (1988).

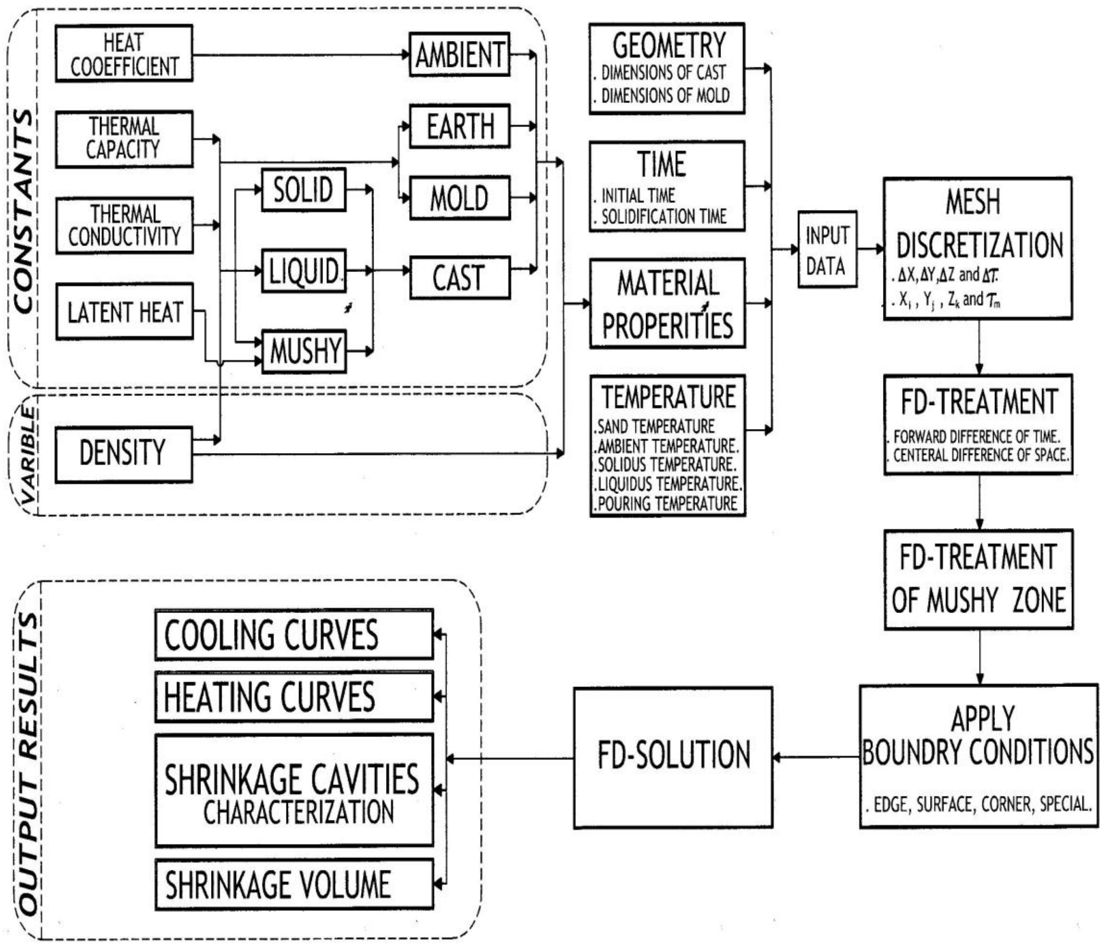

Figure (1) the basic structure of FD-Program

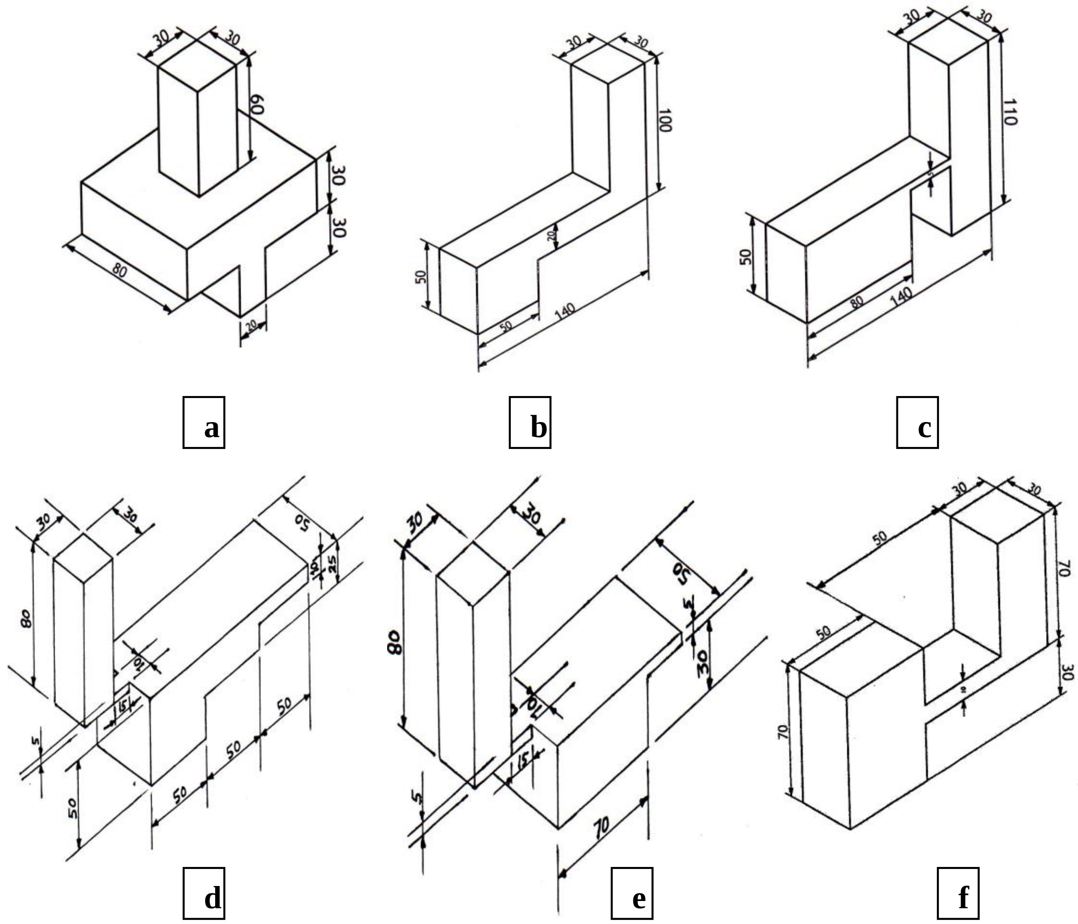

Figure (2) the isometric drawing and dimensions (in mm) of the following cast samples:
a-sample(1) b-sample(2) c-sample(3) d-sample(4) e-sample(5) f-sample(6)

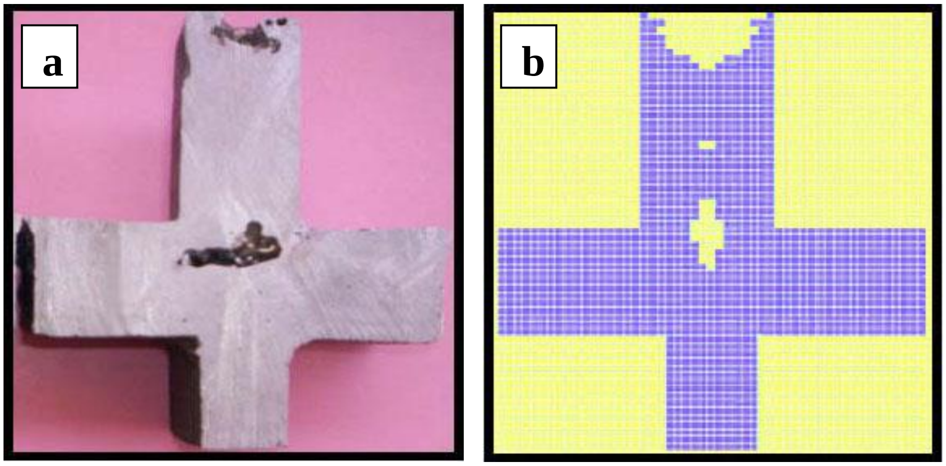

Figure (3) Shrinkage cavity of sample (1), pouring temperature 59

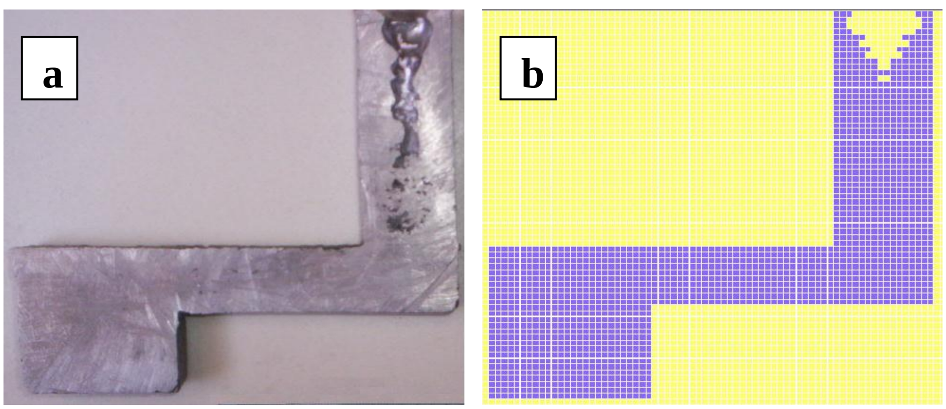

Figure (4) Simulation and experimental results for sample

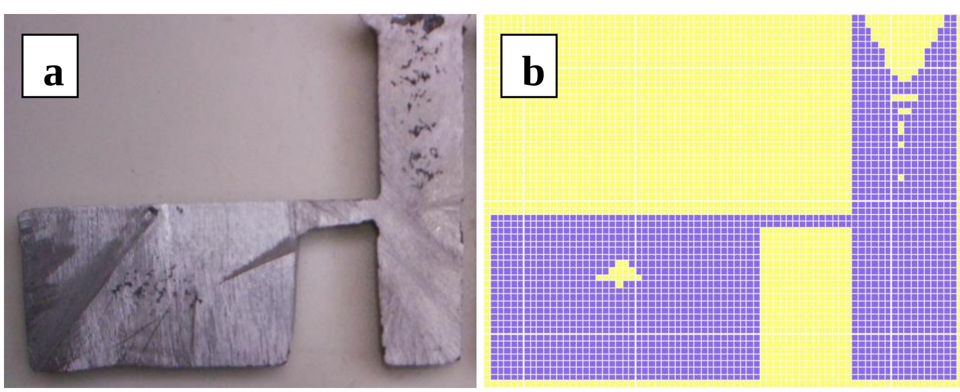

Figure (5) Simulation and experimental results for

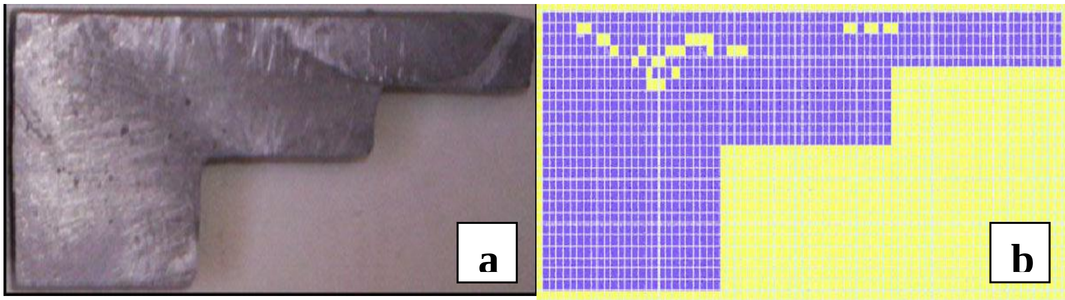

Figure (6) Simulation and experimental results

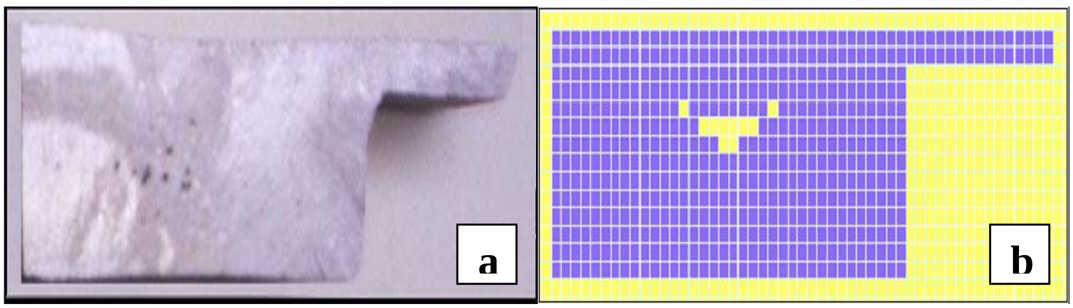

Figure (7) Simulation and experimental results

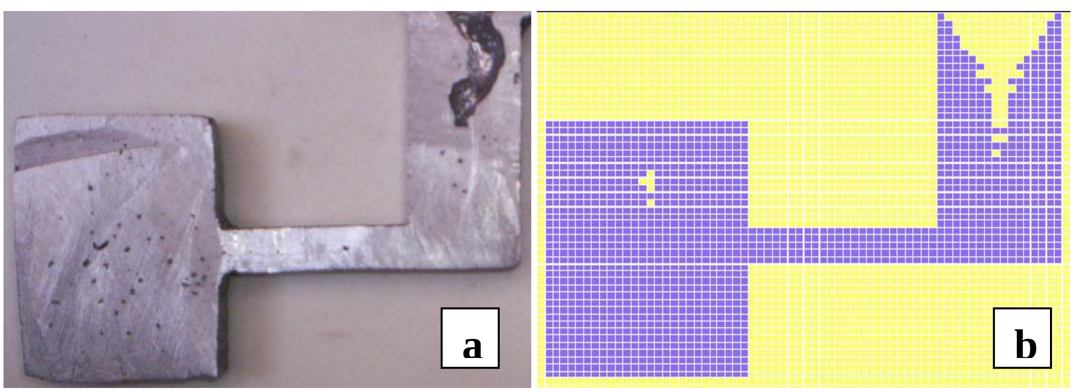

Figure (8) Simulation and experimental

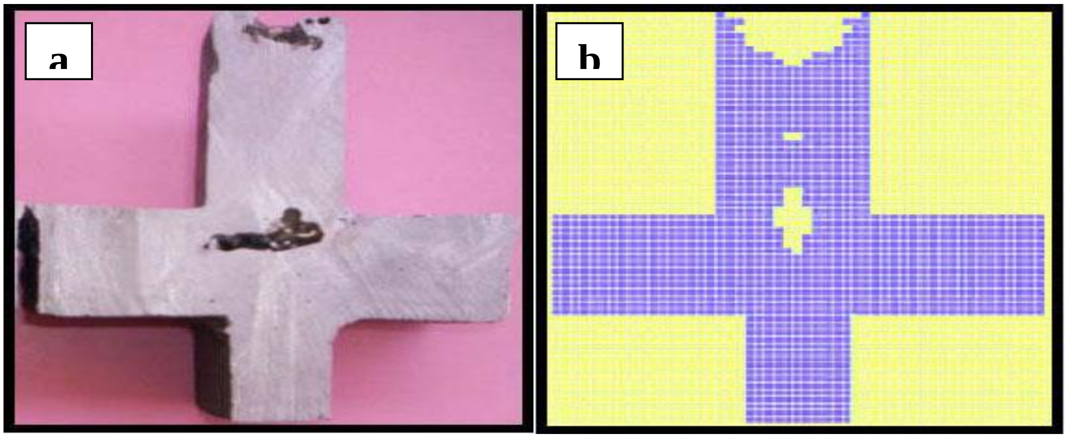

Figure (9) Shrinkage cavity for sample (1), pouring temperature 590 °C, 0.73

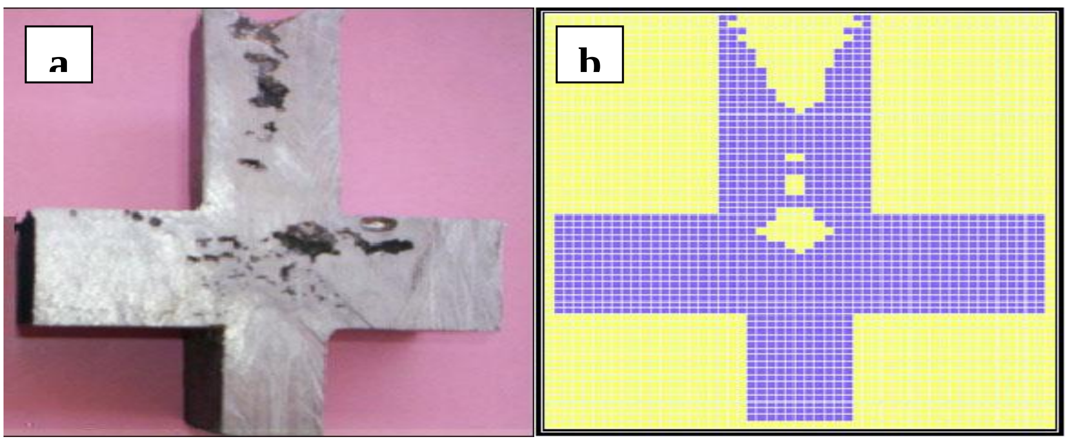

Figure (10) Shrinkage cavity for sample (1), pouring temperature 610 °C, 0.73

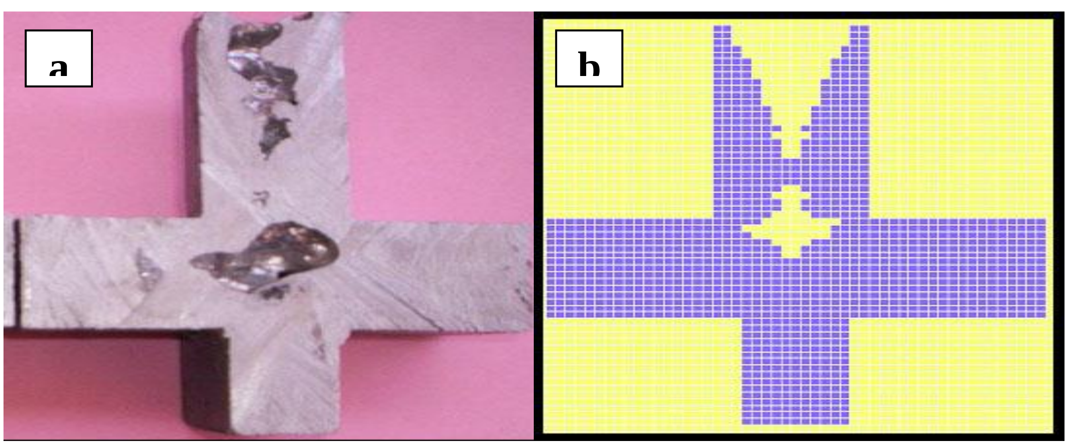

Figure (11) Shrinkage cavity for sample (1), pouring temperature 630°C, 0.73

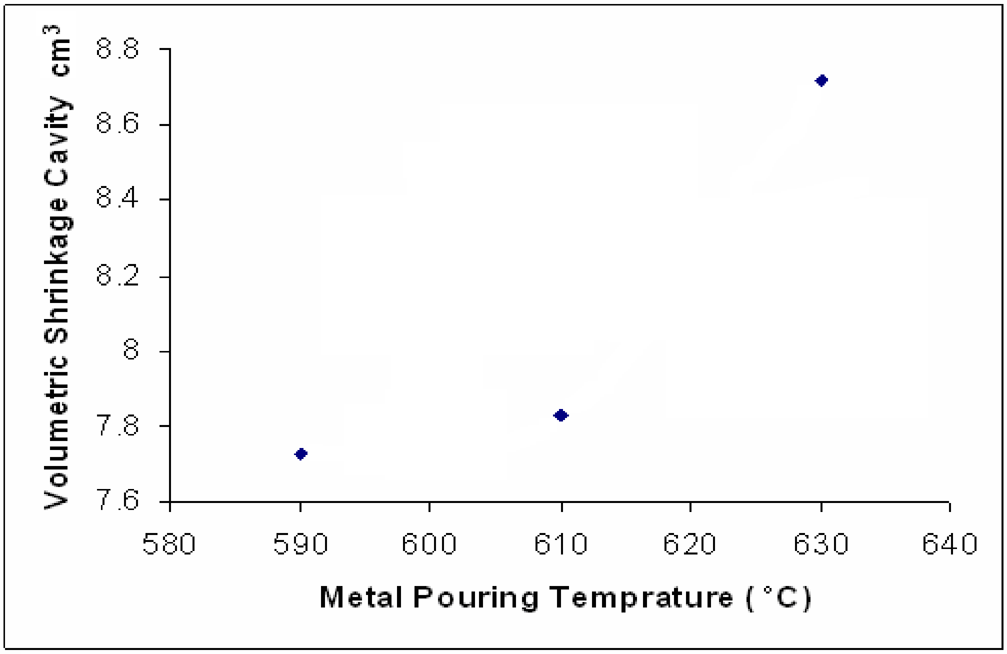

Figure (12) Increase of volumetric shrinkage cavity in cast (1) as metal pouring temperature is increased.

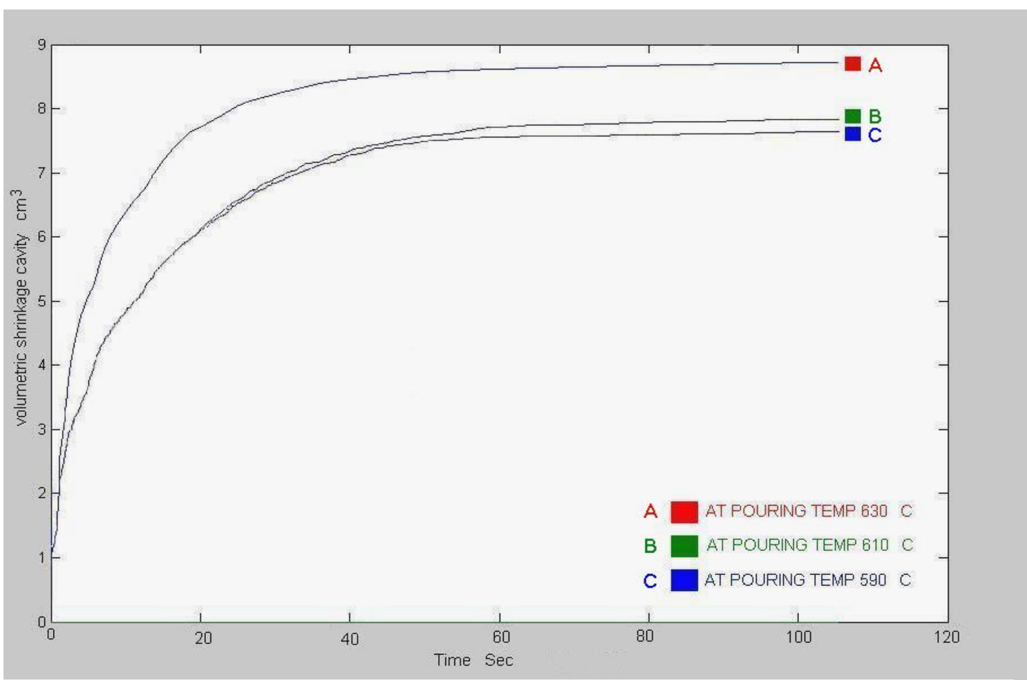

Figure (13) Increase of volumetric shrinkage cavity for cast (1) at different pouring temperature with solidification time.