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MICROSTRUCTURE EVOLUTION OF HYPOEUTECTIC AL – SI ALLOY USING DIRECTIONAL SOLIDIFICATION IN CERAMIC MOLD

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ABSTRACT

Experimental and numerical study has been achieved on a hypoeutectic Al - Si alloy under the effect of directional solidification in ceramic mold chilled with copper. From the coupling between experimental (microstructure evaluation) and numerical (solidification simulation) study, a model is obtained. This model can be used to predict the microstructural features of a hypoeutectic Al – Si alloys.
Key wards: solidification, simulation, microstructure, hypoeutectic, modeling.

تحديد البنية الدقيقة لسبائك ألألمنيوم – سليكون تحت اليوتكتيك باستعمال التجمد ألاتجاهي في قالب سيراميكي

الخلاصة

تم في هذا البحث إجراء دراسة عملية ونظريه على سبائك ألألمنيوم – سليكون تحت اليوتكتيكية بتأثير التجمد ألاتجاهي في قالب سيراميكي بوجود مصقع من النحاس. من خلال التعشيق بين الدراسة العملية (حساب البنية الدقيقة) والنظرية (محاكاة التجمد) تم الحصول على نموذج رياضي. ممكن استخدام هذا الموديل للتنبؤ بالبنية الدقيقة لسبائك ألألمنيوم – سليكون تحت اليوتكتيك.

INTRODUCTION

Studying of the effect of solidification variables on microstructure of casting is important because the as-solidified microstructure dictates heat treatment and the final mechanical performance of the casting. The interparticle spacing (λ) and dendrite arm spacing (DAS) are important microstructural parameters resulting from the solidification process. **[G.phannikumar and K.chattopadhyay,2001]**

The eutectic alloy solidifies and the resulting morphology depends on many parameters. The effect of the thermal gradient and growth velocity are important and had been studied in the past using directional solidification experiments with Bridgman-type furnaces **[Rajiv Sampath, 2001]**. Nevertheless, most of researchers avoid studying irregular eutectic because the relationship between dendrite or eutectic spacing (λ) and solidification parameters are difficult to be experimentally measure for every or most casting area because this needs a large number of thermocouples so that, some studies use the Bridgman furnace to control growth rate or use few thermocouples which cannot cover enough area of casting, and this gives an inaccurate results. The difficulty associated with the modeling of solidification processes arises from the morphological complexity and variety of length-and time-scales in the system **[Wagner palmiere 1998; M.F. ZHU, 2002; M.F. ZHU 2001]**. To overcome these difficulties the present approach used to build and solve macroscopic and microscopic models separately and then couple them to simulate the interactions at different scales.

The aim of this research is to combine between the experimental calculation of dendrite arm spacing (DAS) and numerical simulation of temperature history for hypoeutectic Al-7%Si alloy to find the relation between them.

EXPERIMENTAL PART

A new test mold was specially designed for the experimental part in this study. Rectangular mold made of ceramic material (colleen), a height of 80 mm and a wall thickness of 8mm, and the dimension of cavity 14x14 mm. ceramic material mold used to reduce or prevent transfer of the heat from the mold. The bottom of mold provided with 30x30x25 mm Copper chill to produce unidirectional solidification, as shown in Fig.1.

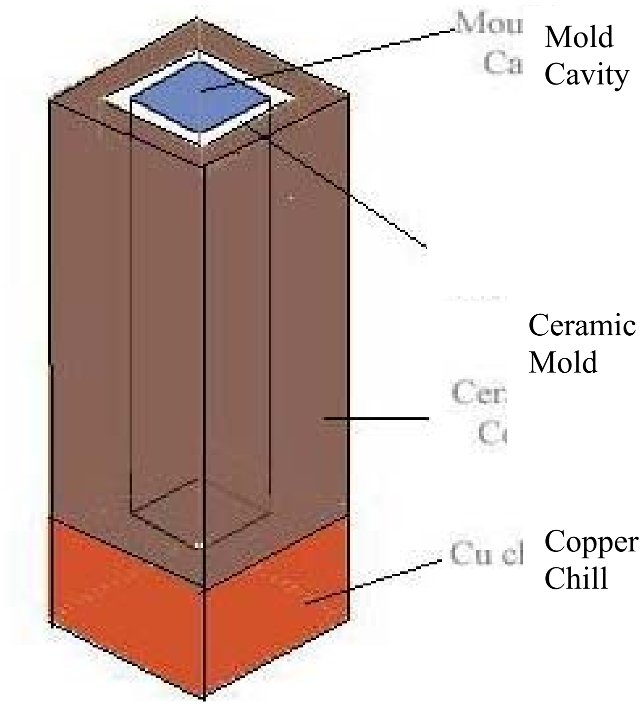


Fig. 1 Dimensions and shape of casting mold, used in current investigation.

Al-7% Si alloy was used in this study. Table (1) gives the chemical composition of this alloy.

Table 1 chemical composition of Al-Si alloys

Alloy type	% Si	% Fe	% Cu	% Mn	% Mg	% Zn	% Ti	% Al
Al-7%Si	7.45	0.02	0.09	0.13	0.001	0.03	0.002	Balance

Thermophysical Data of Alloy

Most commercial casting simulation programs solve the equations of heat transfer in order to produce solidification results. With this being the case, the most important

simulation parameters are those which control heat transfer. The important alloy parameters are the metal density, ρ, specific heat, C_p, thermal conductivity, k, latent heat, L, and solid fraction, f_s.
All of these parameters are a function of temperature. Some of these properties don't change appreciably from one alloy composition to another, allowing the parameter to be generalized to a certain class of alloy.

Table 2 Constant thermophysical properties for alloy **[G. Guillemot, 2004; Kenneth C. Mills, 2002; Ch. Pequet, 2002; R. A. Overfelt, 1997]**

Symbol	Property	Quantity	Unit
ρ_L	Liquid density	2410	kg/m3
ρ_S	Solid density	2650	kg/m3
k_L	Liquid thermal conductivity	65.8	W/m.K
k_S	Solid thermal conductivity	163	W/m.K
C_{PL}	Liquid specific heat	1160	J/kg.K
C_{PS}	solid specific heat	875	J/kg.K
T_L	Liquidus temperature	614	˚C
T_S	Solidus temperature	567	˚C
T_P	Pouring temperature	650	˚C
L	Latent heat	425000	J/kg
k_o	Partition ratio	0.132	/

NUMERICAL METHOD

The ANSYS is a package program that uses finite element method to calculate the numerical solution of complex problems whose analytical solution is tedious or not easy to achieve.

There are many steps to solve the problem by ANSYS these are:

1) Preprocessor :
   ANSYS program can deal with many kinds of problems (mechanical, dynamics, thermal, and fluid) so, the first step mechanical branch has been selected to solve the problem.
2) Processor:
   In this step, the suitable type of elements was chosen to solve the problem, these elements are shown in Fig. 2,

(Solid 70)

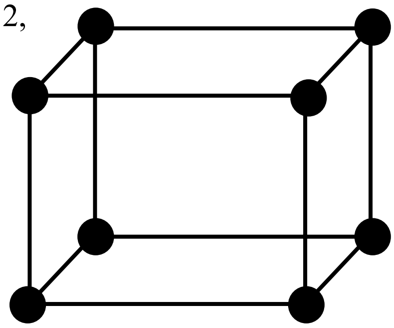


Fig. 2 Element used to solve the problem.

The type of element is Solid 70, to solve this problem needed to have a degree of freedom in the element are temperature and the heat transfer through each face of the element (conduction and convection). Then material properties that are needed to solve this problem are (density, specific heat, and thermal conductivity) in three dimensions with temperature. The drawing of the body in three dimensions is made first, the (1/4) of the body was taken to solve the problem because the symmetry, as shown in Fig. 3, and then the different kinds of materials joined together as a solid material are set.

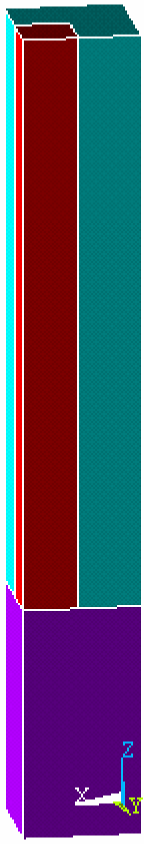


Fig. 3 Three dimensional problem represent (die, chill and the metal): 1/4 of the volume that taken in the ANSYS solution.

The meshing process has been done by using smart, the Fig. 4 represents one-quarter of the three dimension meshing, because a large number of element will cause a long time of solution, so the solution can be done by applying a specific boundary condition.

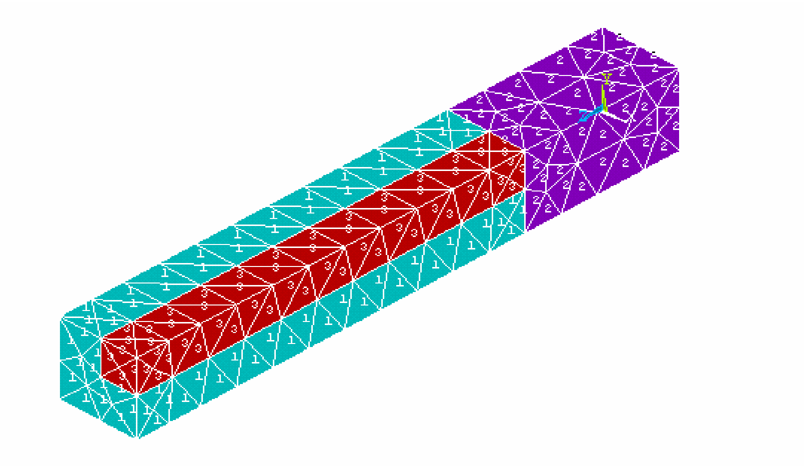


Fig.4 Three dimensional mesh.

3) Solution:

The heat transfer conditions at specific areas of the body are an important to solve the problem. Heat transfer by convection take place from outer surface of mold, chill and top of cast to air. Initial conditions (the temperature of mold, chill, and cast at time = 0 sec was 25 ^{o}C).

Fig. 5 represents the case of heat transfer boundary condition of three dimensions, and one-quarter of the die volume.

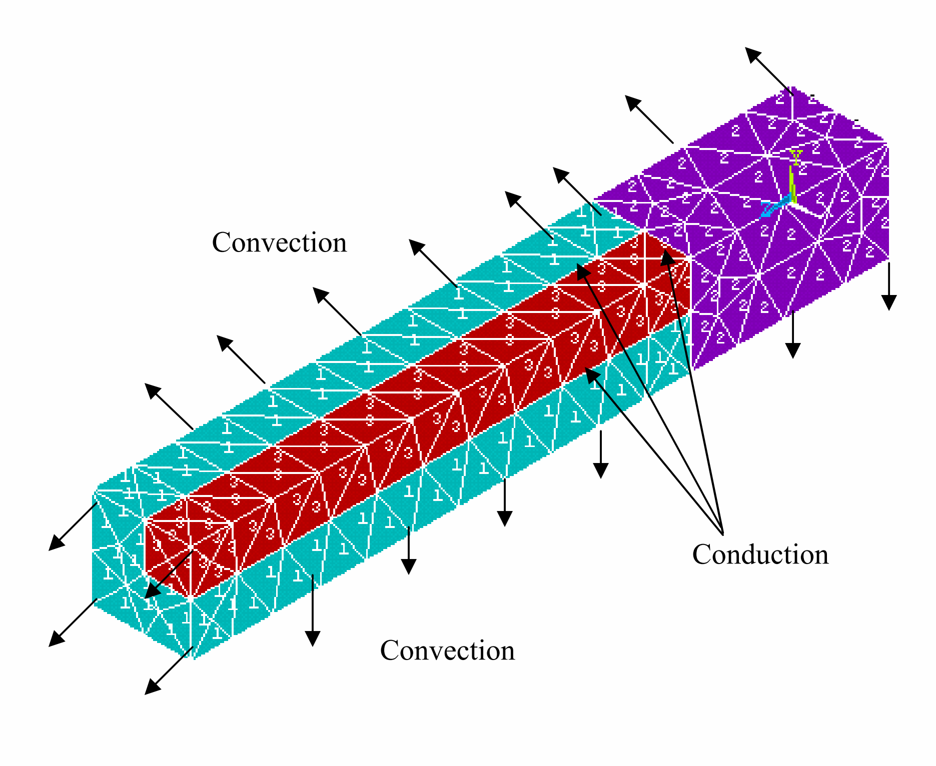


Fig.5 Three dimensional heat flow conditions.

RESULTS AND DISCUSSIONS

The results can be represented as contour plot with temperature distribution at any node, or as paths between temperature and the time at any node in the body as shown in Fig. 6.

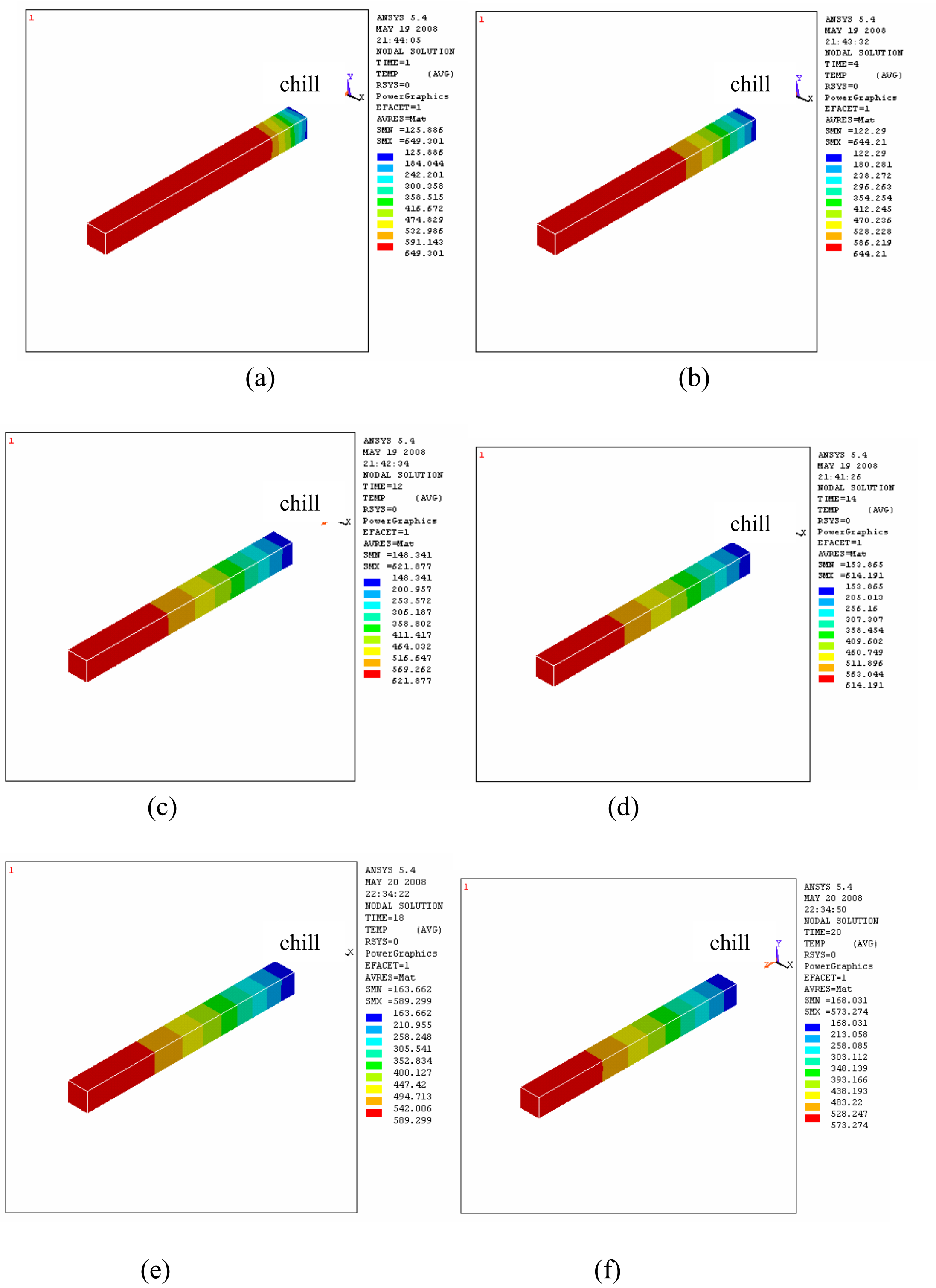


Fig.6 Temperature distribution for cast at different time: (a) 1 sec, (b) 4 sec, (c) 12 sec, (d) 14 sec, (e) 18 sec, (f) 20 sec.

Fig. 6 shown the ANSYS program results after giving the thermophysical properties, i. e. thermal conductivity (k), specific heat (c_p), and density (ρ) for casting Al-7%Si, copper chill, and ceramic mold, then all the dimensions for casting system entered to evaluate the temperature distribution for cast, chill, and mold. To decrease the number of nodes and because the symmetrical of design take quarter of design, this leads to decrease the run time for program.
From this figure, the solid/liquid interface velocity or front growth continues from chill/cast interface to top of mold with time; it can be concluded that due to the behavior of solidification the directional solidification was achieved.

To more verify these results, the cooling curves for casting and heating curves for chill were drawing as shown as in Fig.s 7, 8, and 9. These curves explain that the end of solidification (solidification time) at each selected point from chill/cast interface is increased from point to other toward the top of mold, this means achievement of directional solidification.

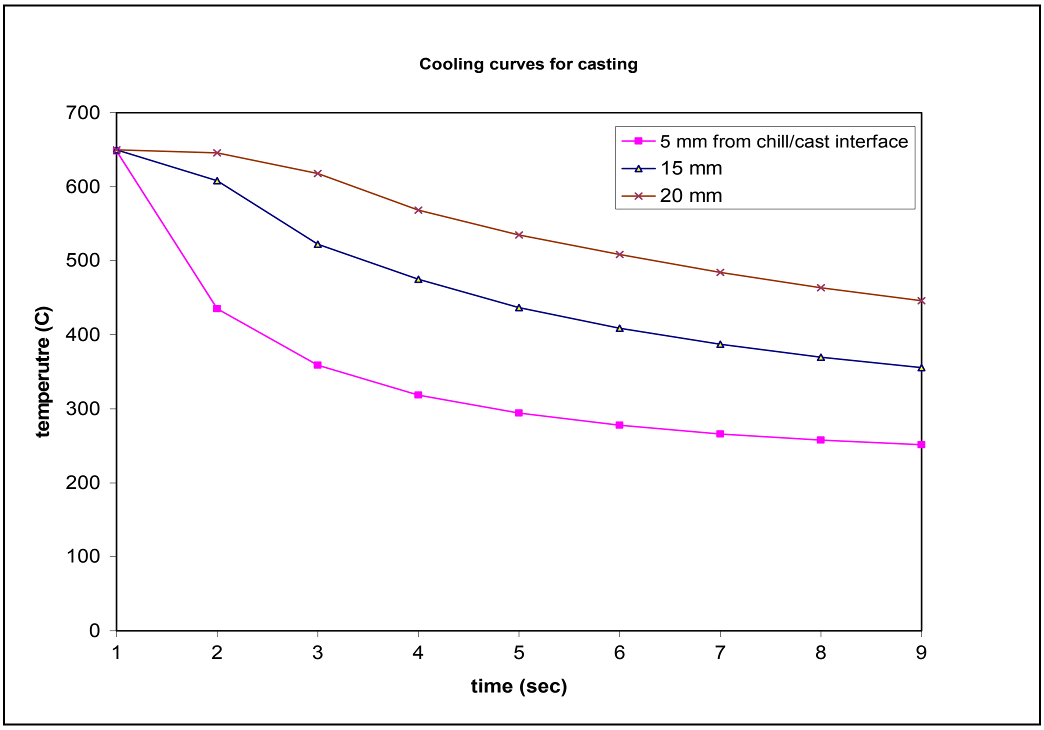


Fig.7 Time-Temperature (Cooling) curves at different locations along casting from chill/cast interface at 5, 15, and 20 mm

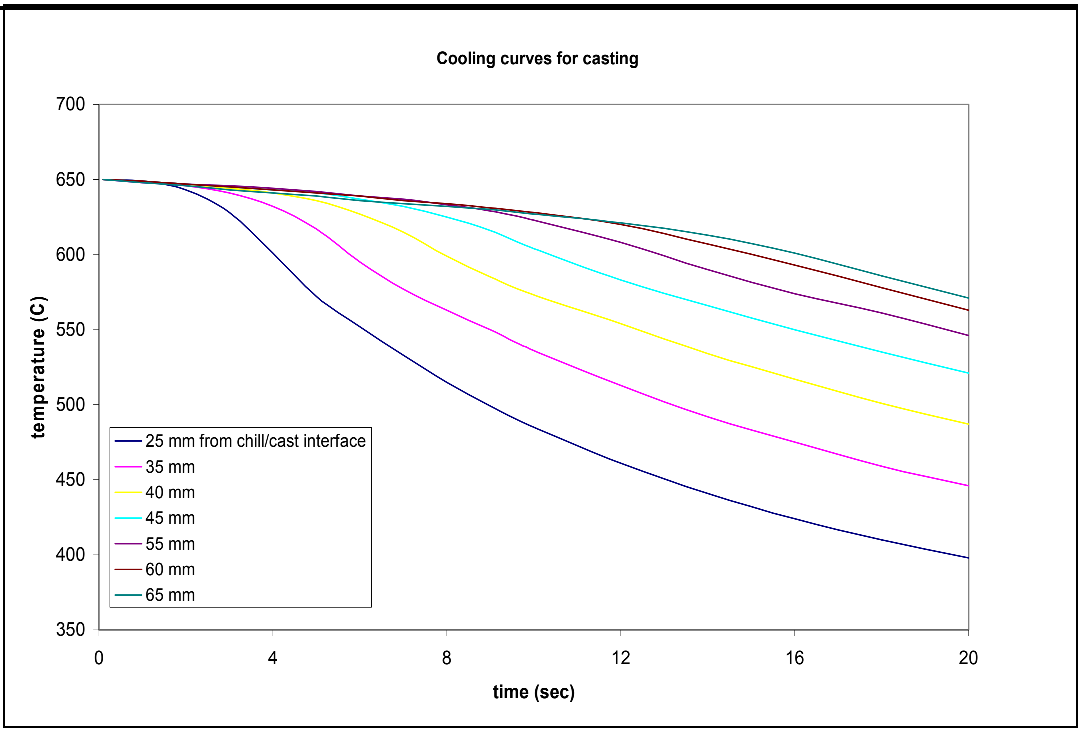


Fig.8 Time-Temperature (Cooling) curves at different locations along casting from chill/cast interface at 25, 35, 40, 45, 55, 60, and 65 mm.

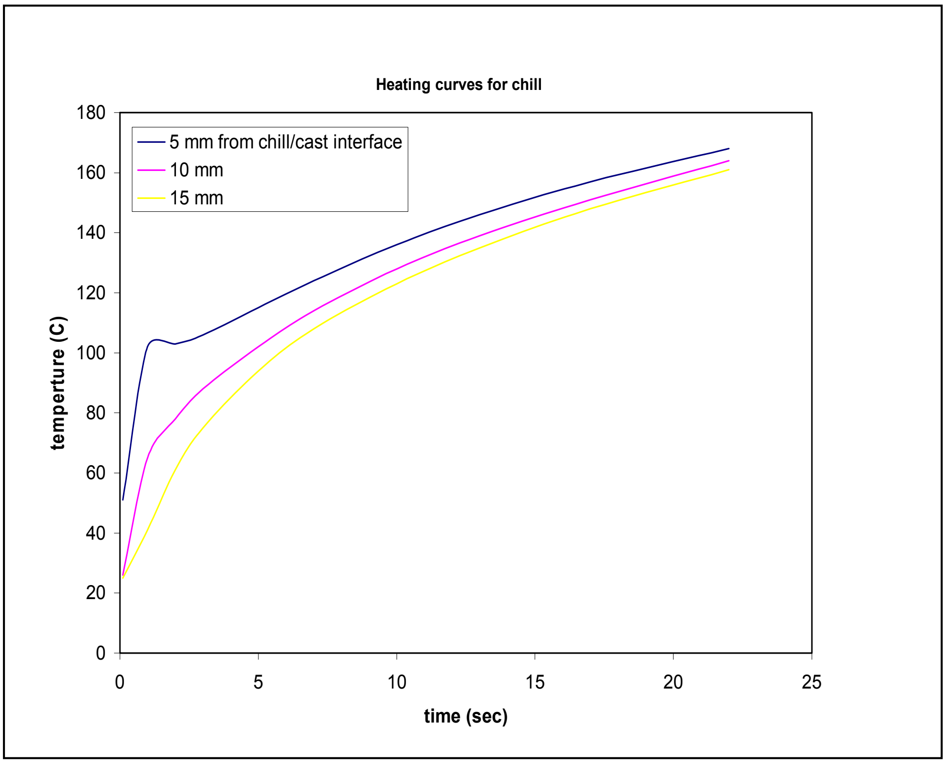
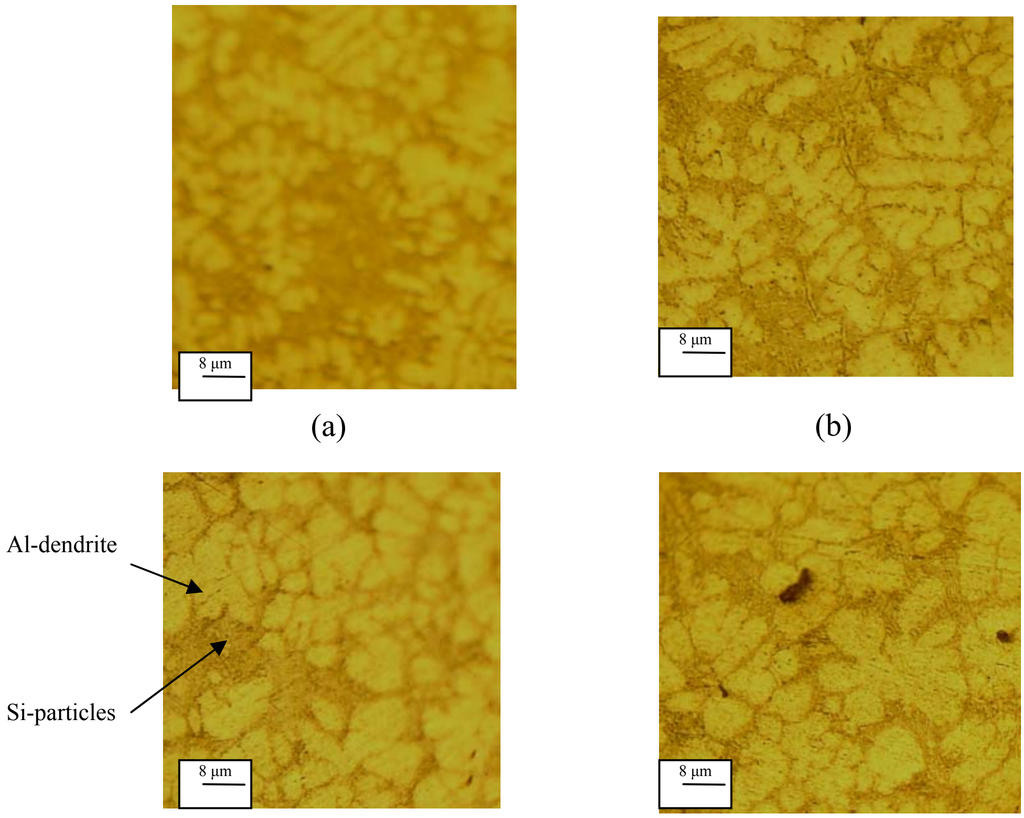


Fig.9 Heating curves at different locations along chill from chill/cast interface.

Microstructural Study of Al-7%Si



(c) (d)

Fig.10 Structure variation of Al-7%Si along the casting with the following distances from the chill , (a) 15 mm, (b) 25 mm, (c) 35 mm, (d) 45 mm.

To built up model explained the relationship between solidification time and microstructure, the microstructure of hypoeutectic Al-7%Si alloy, i.e. Dendrite Arm Spacing (DAS) were measured for distances 15, 25, 35, 45 mm from chill/cast interface Fig. (10), these distances were taken at longitudinal mid surface along cast, then the time of solidification estimation from program and coupled between experimentally microstructure inspection and numerically solidification time estimation Fig.(11) to obtain the relationship as shown below:

$DAS = 1.1689 + 6.525\ t_f$

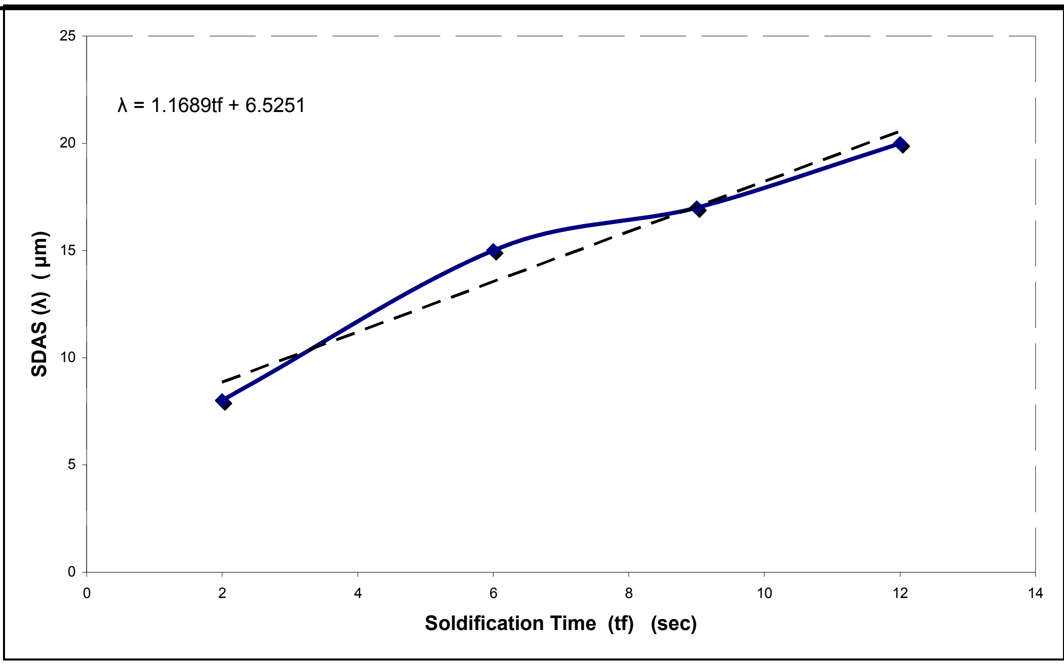


Fig.11 Relationship between secondary dendrite arm spacing (DAS) and solidification time.

CONCLUSIONS

1- The prediction of solidification parameters such as soldification time (t_f) using numerical method approach has been coupled with experimentally microstructure inspection to obtain the following relationship:

DAS = 1.1689 + 6.525 t_f

2- From the simulation of solidification parameters-microstructure relationship, one can predict the microstructual features for any other alloy system after determination the casting conditions and thermal properties of the casting and the mold, and system constituents used.

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Symbols

λ: Eutectic spacing.
ρ: Density.
ρ_L: Liquid density.
ρ_S: Solid density.
C_p: Specific heat.
C_{PL}: Liquid specific heat.
C_{PS}: Solid specific heat.
DAS: Dendrite arm spacing.
f_s: Solid fraction.
k: Thermal conductivity.
k_L: Liquid thermal conductivity.
k_S: Solid thermal conductivity.
L: Latent heat.
T_L: Liquids temperature.
t_f : Total solidification time.