STUDIES ON THE SOLIDIFICATION OF ALUMINIUM-SILICON ALLOYS

THESIS

Submitted To Faculty Of Engineering
Ain Shams University

In Partial Fulfilment Of The Requirement
For The Degree Of Master Of Science

IN

Mechanical Engineering

By

Eng. Emad El-Dien Abd El-Hakiem Abd El-Hady

1994

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MECHANICAL ENGINEERING

SUPERVISORS

Prof. Dr. M. A. Taha

Prof. Dr. N. A. El-Mahallawy

Prof. Dr. A. K. El-Kharbotly

بسم الله الرحمن الرحيم

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EXAMINERS

SIGNATURE

Prof. Dr. A. Al-Ashram

`Prof. Dr. A. S. El-Sabbagh

Prof. Dr. N. A. El-Mahallawy

STATEMENT

This dissertation is submitted to Ain Shams University for the degree of Master of Science in Mechanical Engineering.

The work included in this thesis was carried out by the author in Design and Production Engineering Department, Faculty of Engineering, Ain Shams University, Egypt.

No part of this thesis has been submitted for a degree or a qualification at any other University or Institution.

Date : November, 1994

Signature : Emad Abd El Hakiem

Name : Emad El-Dien Abd El-Hakiem

ACKNOWLEDGMENT

I would like to express my sincere thanks to Prof. Dr. Mohamed A. Taha and Prof. Dr. Nahed El-Mahallawy for their faithful and friendly supervision . The words can not help me to express my great thanks and respect for them .

I would like to thank Dr. Amin El-Kharbotly for his encouragement and help , which were important to present this work in this form. Thanks are also due to Dr. Abdel-Wahed Assar for his useful help when starting this work .

I would like to present special thanks for Prof. H. Fredriksson and Prof. I. L. Svensson at the Department of Casting of Metals , The Royal Institute of Technology , Stockholm , Sweden , where the casting samples were prepared . Their contribution and advices are greatly appreciated .

I would like to thank Dr. M. Abdel-Hameed Abo Aesh and Dr. Ahmed Shaaban for their encouragement and helping in computer work .

I would like to extend my thanks to the technicians at the Metallurgical Laboratory , Faculty of Engineering , Ain Shams University .

Last, but not least , I would like to thank my family for their encouragement to complete this work .

Eng. Emad El-Dien Abd El-Hakiem

SUMMARY

The solidification conditions are very important in controlling the structure and properties of semi and finished metallic products . Casting defects are as shrinkage cavities , porosity are also dependent on the solidification conditions .

In the past a lot of money , effort and time was consumed in conducting several practical casting trials in order to determine the optimum conditions for obtaining the best quality castings . Therefore , modelling and simulation of solidification has been introduced to avoid or reduce the practical trials prior to the production . These models are either macroscopic (heat flow) , microscopic (kinetic) or macroscopic-microscopic . The last models (macroscopic-microscopic) which are based on the combination of both heat flow and kinetic have been proposed only within the last few years . Such models have been applied to several alloys as cast iron , Al-Si and Al-Cu alloys , especially the eutectic composition of these alloys for the simplicity of their structure compared to the dendritic one .

In general , the Al-Si structure is difficult to describe using the simulation models as this structure is very sensitive to the solidification conditions . Different types of structure appear at the same time in this alloy . Therefore , the field of solidification simulation in Al-Si alloy still need a lot of work . Accordingly , it is the idea to consider the Al-Si alloy for the present work .

Al- 7.5 wt.% Si , Al- 9.17 wt.% Si , Al- 9.5 wt.% Si , Al- 12 wt.% and Al- 18 wt.% Si are used in the present work . These alloys have been solidified in sand and metallic moulds with different thicknesses in order to obtain different solidification conditions . Cooling curves have been recorded during the casting of samples which have been conducted in the Department of Casting of Metals in the Royal Institute of Technolgy , Stockholm , Sweden.

In this research , analysis of the cooling curves is made and the solidification parameters determined are related with the microstructure observed for the different alloy compositions . A microscopic solidification model is established and numerical simulation is applied on the Al- 12 wt.% Si (eutectic alloy) . The solidification growth constant (μ) for Al-Si alloy and the values for heat transfer coefficient at metal/mould interface for different casting conditions have been determined .

INTRODUCTION

The solidification of metals is very important process to control the properties of both semi and final products . In the past , many experimental trials should be made in order to produce free-defect products . These trials cost a lot of effort , money and time . The simulation of solidification process , using different models has started for thirty years . These models used to study the solidification of metals in details in order to predict the defects of the casting which affect directly the casting properties .

Some of the models were designed to describe the microstructure . As the microstructure of Al-Si alloys is complicated , it is difficult to be described by using those models .

In the last few years , modern models were available to study the macrostructure and microstructure . These models are either macroscopic (heat flow) [1] , microscopic (kinetics) [2] or macro-microscopic [3] . Through the survey of previous work , it is clear that this field is still virgin and necessarily need more developements . Therefore , it is the idea in this work to set up a model to study the solidification of Al-Si eutectic alloy . This model is applied on samples of Al- 12 wt.% Si which were cast and their cooling curves were recorded at the Department of Casting of Metals, The Royal Institute of Technology, Stockholm , Sweden .

Another part of the present work is studying the microstructure of different Al-Si alloys including in addition to the eutectic composition other hypoeutectic and hypereutectic compositions . The alloy compositions considered which were cast in both metallic and sand moulds , are Al- 7.4 wt.% Si , Al- 9.17 wt.% Si , Al- 9.5 wt.% Si , Al- 12 wt.% Si and 18 wt.% Si . Different casting thicknesses were used to change the solidification conditions . Some microstructure-parameters as dendrite arm spacing and volume fraction of primary phase were measured .

The main results of this work are relating between both dendrite armspacing and volume fraction of primary phase with cooling rate , solidification rate and solidification time . From the solidification model the growth constant are deduced for Al-12 wt.% Si composition and the heat transfer coefficient of the gap between casting and mould are estimated to give good fitting between the experimental and calculated cooling curve . The calculted grain size and measured one from the samplesare almost the same , this is the other main success of this model .

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CHAPTER (1)

LITERATURE SURVEY

1.1 INTRODUCTION :-

Aluminium - silicon alloys containing 2 - 25 wt.% are widely used in industery . They are used particulary in pistons , connecting rods and casting of motor engines . They have considerably high corrosion resistance . The addition of Si element imparts fluidity and high mechanical properties . The yield strength , ultimate strength and Vickers hardness increase sharply with increasing the silicon content up to about 5 wt.% Si [4] . Due to the high fluidity of Al-Si alloys , they can be cast in sand or by pressure die casting . One of the main advantages of using silicon as alloying element is that the addition of silicon improves the properties without loss of weight . This is due to the fact that the specific gravity of silicon is 2.3 grm/m^3 and that of aluminium 2.7 grm/m^3 . For the foregoing reasons , Al-Si system is considered in this due to its superior properties .

1.2 ALUMINIUM - SILICON SYSTEM :-

The aluminium - silicon system is simple eutectic with partial miscilbity in solid state as shown in the equilibrium diagram given in Fig. (1.1) .The eutectic temperature is generally accepted as 850 K (or 850.2 K) . The composition at the eutectic point has been reported to contain Si ranging from 11.7 wt.% to 14.5 wt.% .The Si content at equilibrium condition is most probably to be 12.5 wt.% [4] .

Solidification conditions , such as cooling rate and pressure have remarkable effects on the eutectic point composition and the extent of solubility of silicon in aluminium . Rapid quenching from the liquid raises the solubility up to 16 wt.% Si and shifts the eutectic point up to 17 wt.% Si [4] . Pressure in the order of 3 GN/m^2 shifts the eutectic position and temperature to above 25 wt.% Si and 1300 K and increases the solubility to 7 wt.% Si [4] . As reported by Hellawell [5] the eutectic point composition is 11.7 wt.% Si and the eutectic temperature is 850 K Subsequent determinations with purer materials confirmed slightly higher value above 12.5 wt.% Si .

Gayler , as reported by Hellawell [5] has indicated how primary silicon would undercool further below the liquidus temperature than would aluminium . The fine two-phase strucuture might form at as much as 10 - 20 K below the accepted eutectic temperature with the " eutectic point " apparently shifted to higher silicon content by 1 - 2 wt.% Si .

It appears from Gayler's work and subsequent reports that the depression of eutectic arrest on cooling at rapid rates does not exceed ~ 10 K , i.e. this might be the order of undercooling at freezing rates of the order 0.1 cm/sec. which might be expected in small chill castings . The arrest did not show recolescence such as would be expected if the depression was the result of delayed nucleation only , nor is the eutectic arrest on heating curves ever depressed below the apparent equilibrium temperature of 850 K. Thermal arrests with rapid cooling fall below the equilibrium liquidus as shown in Fig. (1.2) [5] , and as may be seen , the silicon undercools at high rates more than aluminium so that , the eutectic point is displaced more than 1 wt.% to higher silicon concentration , as would be expected for coupled growth in such a system [5] .