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Ain Shams University
Faculty of Engineering

STUDY OF SOLIDIFICATION MECHANISM IN CASTING BY RAPID SOLIDIFICATION PROCESS

A thesis submitted for the Ph. D. degree in
Mechanical Engineering
Production Engineering

By

ENG. TALAAT AHMED MOHAMED EL-BENAWY
B. Sc., M. Sc. Mechanical Engineering

Presented to
Faculty of Engineering
Ain shams University

Supervised by:

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بسم الله الرحمن الرحيم

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STATEMENT

This dissertation is submitted to Ain Shams University for the degree of philosophy in Mechanical Engineering (Production Engineering).

The work included in this thesis was carried out by the author according to the Egyptian channels system between Department of Design & Production Engineering, Faculty of Engineering, Ain Shams University, and Department of Materials Processing, Casting of Metals Division, Royal Institute of Technology, Stockholm, Sweden, from 1989 to 1995.

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

Date: 29/4/95

Signature: Talaat

Name: Talaat Ahmed El-Benawy

TO THE MEMORY OF MY PARENTS

AND

TO MY WIFE

ACKNOWLEDGEMENT

I would like to express my deep thanks and appreciation to my supervisors *Prof. **H. Fredriksson** of Royal Institute of Technology, Sweden, Prof. **M. Taha** and Prof. **N. El-Mahallawy** of Ain Shams University* for their guidance, support and encouragement.

I wish also to thank ***all members of Department of Materials Processing, Royal Institute of Technology, Stockholm, Sweden***, for giving me all assistance during the work with thesis.

Thanks are also due to ***all members of Metallurgy Lab. of Faculty of Engineering, Ain Shams University***, for their cooperation during the work.

I Should also express my warm thanks to *my wife **Ibtehal*** for her patience and support during the work with thesis.

The author also indebted to all who have offered any direct or indirect help.

SUMMARY

In the present work, the microstructure and the solidification conditions of the rapidly solidified Ag-Cu and Al-Cu lamellar eutectic alloys, have been studied. The experimental work includes the preparation of three alloys representing the hypo-eutectic, eutectic and hyper-eutectic compositions for each alloying system. Levitation casting technique was used in order to achieve the concept of rapid solidification. Simple pouring casting technique was additionally used for Al-Cu alloys in order to produce a wide range of interlamellar spacing and undercooling. The cooling curves were recorded during the experimental work and the values of the cooling rate and the corresponding undercooling were calculated and correlated together. Simple heat flow model have been used in order to calculate the growth rate during the solidification of the Al-Cu alloys.

The thermodynamic basis of the phase diagram calculation incorporated with the lattice faults that can be arisen due to rapid solidification were used in order to establish a new eutectic growth model. Finally, the proposed lamellar eutectic growth model was verified through the experimental results of the $Al\text{-}Al_2Cu$ lamellar eutectic.

The main experimental results indicated the ease with which the Ag-Cu lamellar eutectic alloys can be solidified with non-lamellar morphology by using rapid solidification. For $Al\text{-}Al_2Cu$ alloy, the λ-v relationship was found to follow the same relation given in previous work, while the ΔT-λ and ΔT-v relationships were found in disagreement with the relations of previous work. Increasing lattice defect led to a deviation in the equilibrium phase diagram of the $Al\text{-}Al_2Cu$. Accordingly, a new undercooling term, ΔT_{eq}, was added into the general undercooling equation, then it was possible to recalculate the theoretical relations of λ-v, ΔT-λ and ΔT-v by considering that the eutectic lamellar growth will be at the minimum undercooling condition as previous work have been indicated. These relationships were successfully verified through the experimental results of ΔT, v and λ.

CONTENTS

INTRODUCTION

The application of different cooling rates on crystalline metals and alloys is a well-known method for producing different scales of microstructure. The high cooling rates achieved by rapid solidification technique, leads to the increase in the solubility limits, the refinement of the microstructure as well as improving the electrical, magnetic and mechanical properties. The different microstructure morphologies developed from rapid solidification are always controlled by the amount of the attainable undercooling and growth rate. In some cases, microsegregation-free and amorphous structures can be obtained at very high cooling rate.

Numerous investigators have studied the microstructure variation of the rapidly solidified metals and alloys. Eutectic alloys, especially, have been the subject of several investigations. Ag-Cu and Al-Cu eutectic alloys, are the most lamellar binary ones that have been used as a model system for studying the solidification behavior of lamellar eutectic growth. However, there still a lot of work needed in order to understand the mechanism of solidification especially in the case of rapid solidification.

Therefore, the present work was devoted to study the solidification mechanism of the rapidly solidified Ag-Cu and $Al\text{-}Al_2Cu$ eutectic and near to the eutectic alloys. Three alloys representing the hypo-eutectic, eutectic and hyper-eutectic alloy, are prepared for each system. Levitation and pouring casting techniques were applied in order to perform the concept of rapid solidification. The cooling curves are recorded during the experimental runs. The cooling rate and the undercooling are measured from the recorded curves.

For Ag-Cu alloys, the microstructure of the solidified samples are extensively examined using the optical and scanning microscopes. Attempts are made in order to correlate the obtained microstructure with the solidification condition.

For Al-Al_2 Cu alloys, it was possible to establish the kinetic relations which represent the interlamellar spacing-growth rate, undercooling-growth rate and undercooling-interlamellar spacing relationships by using a simple heat flow model in order to calculate the growth rate. A lamellar eutectic growth model was proposed by adding a new undercooling term into the general undercooling equation. This term was calculated based on the thermodynamic of the phase diagram calculations incorporated with the lattice faults that can be arisen due to rapid solidification. The proposed model is verified through the experimental results.

CHAPTER 1

LITERATURE SURVEY

1. 1 Rapid Solidification Processing

1. 1. 1 Introduction

In the last four decades significant advances have been made in the field of rapid solidification. The initial stimulus for the field of rapid solidification came from Pol Duwez's report [1] in 1960. Pol Duwez has used the gun technique, Fig. 1.1, in order to achieve the concept of the rapid solidification. He has found that normal two phase mixture of an equilibrium eutectic alloy could be replaced by either an extended solid solution, a new crystalline phase and/or non-crystalline phase (i. e. glass), simply by quenching, with sufficiently high cooling rate, from the liquid state. The rapid solidification is most readily achieved by imposing a high cooling rate of order 10^2 to 10^{10} K. sec^{-1}. This, of course, requires sufficiently good contact of a sufficiently thin section of melt with a highly conductive heat sink. Comparing with the conventional solidification, the rapid solidification has the following particular characteristics [2]: (i) large departures from the equilibrium constitution, (ii) more uniform and size refined solidification, (iii) elimination of the redundant working and finishing operations. Generally, it has been became clear now that under the conditions of rapid solidification of the metals and alloys it is possible to: refine the microstructures, extend the solid solubility, produce a non-equilibrium and/or metastable phases and, at a certain level of very high cooling rate, amorphous solids can be formed. These characteristics improve the mechanical, electrical, chemical, and magnetic properties of specified metals and alloys.

In the following sections, the different techniques of the rapid solidification processing and the microstructures that can be obtained from such techniques, will be given. The principles of the rapid solidification as well as the features

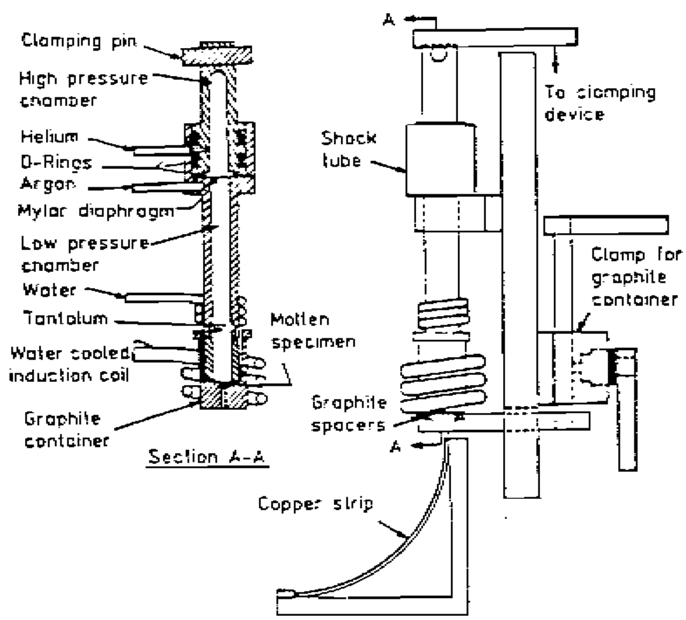

Fig. 1.1 Gun technique of Duwez for rapid solidification [2].