

CASTING AND SOLIDIFICATION OF  
SEMI-SOLID ALLOYS

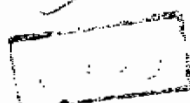
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CASTING AND SOLIDIFICATION OF  
SEMI-SOLID ALLOYS

Ph.D. THESIS  
IN  
MECHANICAL ENGINEERING  
(Production Engineering)

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*To my late father, who encouraged and assisted me strongly in life, to my mother and to my dear wife whose love and support enabled me to work hard.*

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## SUMMARY

This work has the aim of modelling the heat flow and analysing the rheology of the semi-solid slurry inside the stirring chamber of a continuous rheocaster, then verifying both experimentally. For this purpose a continuous rheocaster suitable for Bi-2201 model alloy system and operating at practical values of processing parameters, has been designed and constructed.

The processing variables considered are : the shear rate  $\dot{\gamma}$  imposed in the rheocaster (RC) slurry, ranging from  $270 \text{ s}^{-1}$  to  $10^3 \text{ s}^{-1}$ , slurry flow rate  $\dot{Q}_p$ , ranging from  $4.5 \times 10^{-3}$  to  $10^{-3} \text{ Kg/s}$  and the input temperature  $T_i$ , ranging from 500 to 600 K.

The heat flow in the stirring chamber of the continuous rheocaster is studied using a two - dimensional dynamic heat transfer model and solving it numerically.

The rheological behaviour of the alloy slurry in the stirring chamber is studied analytically and experimentally. Semi-empirical relationships for the influence of structure and shear rate induced in the slurry  $\dot{\gamma}$ , on the apparent viscosity  $\eta_a$  are derived. Structure parameters considered are : volume fraction of primary solid particles  $G_s$ , average particle size  $d_p$  and solid-liquid interface area per unit volume of the slurry  $S_v$ .

the slurry flow rate  $\dot{Q}_m$  in terms of stirrer radius  $R_1$ , the inner radius of the stirring chamber  $R_2$  and the slurry apparent viscosity  $\eta_a$  is obtained.

this work new awareness has been established about the relationships between the parameters influencing the rheocasting process which are valuable in the future work.

The main results obtained can be summarised as follow :

Exit temperature at the exit port of the continuous rheocaster,  $T_{exit}$  : it increases with increasing  $\dot{Q}_p$  and  $T_i$  and decreasing the number of cooling coils per unit height of stirring chamber,  $N_g$  and its height,  $L$ .

Primary apparent viscosity,  $\eta_a$  : it increases with increasing  $\lambda_m$  and  $S_v$ . It decreases with increasing the shear rate,

Microstructure : 1)  $G_s$  increases with decreasing  $\dot{Q}_p$  and 2)  $\lambda_m$  decreases with increasing,  $\dot{\gamma}$  and the primary cooling,  $\dot{\xi}$ . 3)  $S_v$  decreases with increasing,  $\dot{\gamma}$  and decreasing  $\dot{\xi}$ .

Each results will be useful in designing the continuous rheocaster as well as in determining the suitable processing conditions.

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## INTRODUCTION

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## INTRODUCTION

The rheocasting process uses a partially solidified alloy as a charge and thus differs from other commercial metal-shaping processes which use either fully liquid (conventional casting) or fully solid alloy (conventional forming). The process consists of vigorously agitating the alloy in the solid-liquid temperature range, to produce a highly fluid semi-solid slurry.

Rheocasting processes are either batch or continuous.

Continuous rheocasting is more convenient for practical applications, and is more advantageous than batch rheocasting. Most of the published work on rheocasting was directed towards, studying experimentally the effect of process variables on the viscosity of rheocast alloy slurries, the structure of completely solidified rheocast materials, and mechanical properties. Previous work<sup>(1-24)</sup> have shown that the process is promising so that it can lead to a novel structure, improved soundness and homogeneous chemical composition and mechanical properties. On the other hand, the process seems to be economically promising due to low energy consumption, better die life, possibility of casting high temperature alloys into dies. Advantages are gained since low temperature is used compared to conventional casting.

In spite of all these advantages, it is still too difficult to apply the process technically. Indeed much better theoretical understanding of the process is needed in order to be able to

rol it and therefore apply it technically.

It is the aim of the present work, which is a part of a arch program in the metal casting laboratories - Ain-Shams ersity, to touch these area of research. This work includes lling of the heat flow and analysis of the rheology of semi i Bi-17%wt Sn alloy slurry inside the stirring chamber of ontinuous rheocaster, then verifying both experimentally. For the experimental work, a continuous rheocaster was des- i and constructed. A numerical model is presented which simulate the temperature fields in the alloy contained in stirring chamber. The results agree well with measurements. model is also used to predict some relationships between process parameters in continuous rheocaster analytical models are also derived for describing the ogy of partially solidified Bi-17%wt Sn alloy slurry . elationships obtained in this work between the parameters g in the rheocasting process throw more light on the standing of the process and may represent a step forward pproaching the practical application of it.

## **CHAPTER 1**

### **LITERATURE SURVEY**

## CHAPTER I

### LITERATURE SURVEY

The process of rheocasting was started in 1949 by Wheelwright in England, who used it for producing permanent moulds. However, the process started to be known on scientific basis later on by Flemings<sup>(1-9)</sup> in the MIT in 1971, whose work opened new areas for both science and technology. A histogram in figure(1.1) shows the distribution of the number of publications on the process appeared in the period (1950-1985). Flemings et al found that when metal alloys are vigorously agitated during solidification they form slurries of low viscosity, even at fraction solid as high as 0.6. Several different names have been given which are : rheocasting, stirring, casting of semi-solid alloys and casting of partially solidified alloys. The process includes the production

#### Types of rheocasting apparatus

The rheocast slurry can be produced as a unique batch in a stirred vessel. In this case the stirred slurry has to be poured into the mould as in conventional casting. Another technique has been developed by Flemings et al<sup>(10)</sup> is the production of continuous rheocast slurry. In the batch type, the normal procedure was to heat the alloy above the liquidus temperature. The stirrer was then lowered in the melt, and stirring begins as shown in figure(1.2). The temperature of