UNIVERSITI PUTRA MALAYSIA

THERMAL ANALYSIS OF TWO AND THREE-GATE SAND CASTING MOULD

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By

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A study of thermal characteristics of the molten metal in sand casting process had been carried out. This comprises of experimental work and modeling of casting process. Two sand molds are fabricated using the carbon dioxide-silicate method. One of them has 2 gates and the other one has 3 gates. Data of temperature distribution can be obtained by detecting the temperature changes at thermocouples from various predetermined location of the sand mold. Presence of molten metal can be known by observing the drastic changes of temperature at a particular point and therefore the flow characteristics was studied. The data is presented in a graphical format and is compared with the calculated result produced from modeling program called Thermnet. The Thermnet program is a simulation program for thermal analysis. This simulation program is Network technique based. Comparison of modeling and experimental results are also presented. Finally, base on these data, weak point of the sand mold design is being pointed out and proposal for a better design is made.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENGAJIAN TERMA PROSES PENUANGAN PASIR UNTUK ACUAN-ACUAN 2-GATE AND 3-GATE

Oleh

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Satu kajian mengenai taburan terma leburan logam dalam proses penuangan pasir telah dijalankan. Ia terdiri daripada kerja-kerja experimen dan pemodelan proses penuangan tersebut. Dua acuan pasir telah dibuat dengan menggunakan cara karbon-silika. Salah satunya mempunyai 2 gate dan satu lagi mempunyai 3 gate. Data bagi taburan suhu boleh didapati dengan mengesan perubahan suhu pada termo-gandingan yang diletakkan pada bahagian-bahagian acuan yang berlainan. Ketibaan leburan logam boleh diketahui dan dikaji melalui pemerhatian perubahan suhu yang mendadak. Data-data ini akan diwakili oleh carta-carta grafik dan ianya dibandingkan dengan data yang diperolehi melalui kiraan, melalui perisian komputer ThermNet, yang digunakan untuk mengkaji suhu tuangan leburan logam. Perisian tersebut adalah berdasarkan teknik rangkaian. Akhirnya, berdasarkan data yang diperolehi, kelemahan-kelemahan acuan pasir tersebut dapat ditunjukkan dan reka-bentuk acuan yang lebih baik telah dicadangkan.

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LIST OF ABBREVIATIONS AND NOTATIONS

Si	-	Silicon
Al	-	Aluminium
Mn	-	Manganese
C	-	Carbon
Cu	-	Copper
P	-	Phosphorus
S	-	Sulfur
Zn	-	Zink
h	-	elevation above a certain reference plane (m)
p	-	pressure (N/m^2)
L	-	length (m)
m	-	mass (kg)
q	-	heat flow (W)
α	-	heat transfer coefficient ($W/m^2 °C$)
ρ	-	density of fluid (kg/m^3)
g	-	acceleration of free fall (m/s^2)
v	-	velocity (m/s)
f	-	frictional loss (W)
Q	-	flow rate (m^3/s)
A	-	cross section area (m^2)
V	-	velocity (m/s)
Re	-	Reynolds number

D	-	diameter of a channel (m)
η	-	viscosity (kg/ms)
DT	-	temperature difference (°C)
T_S	-	temperature when solidification is complete (°C)
T_L	-	temperature when melting is complete (°C)
k	-	loss coefficient
K	-	thermal conductivity (W/m°C)
FD	-	finite difference
FE	-	finite element
FEM	-	finite element method
BE	-	boundary element
CAD	-	computer aided design
CAA	-	computer aided analysis

CHAPTER 1

INTRODUCTION

1.1 Background of Casting

Casting is defined as the process whereby molten material is poured or forced into a mould and allowed to harden. When the metal solidifies, the result is a casting - a metal object conforming to that shape. A great variety of metal objects are also moulded at some point during their manufacture [1].

The most common type of mould is made of sand and clay; ceramics, sand with cement, metals, and other materials are also used for moulds. These materials are packed over the face of the pattern (usually made of wood, metal, or resin) that forms the cavity into which the molten metal is to be poured. The pattern is removed from the mould when its shape is able to be retained by the mould material. Moulds are usually constructed in two halves, and the two halves are joined together once the pattern has been removed from them. Pins and bushings permit precise joining of the two halves, which are enclosed in a mould box. The metal is then poured into the mould through special gates and is distributed by runners to different areas of the casting. The mould must be strong enough to resist the pressure of the molten metal and sufficiently permeable to permit the escape of air and other gases from the mould cavity; otherwise, they would remain as holes in the casting. The mould material must also resist fusion with the molten metal, and the sand at the mould surface must be closely packed to give a smooth casting surface [2].

The making of patterns for foundries requires care and skill. Patterns are uniformly larger than the desired casting in order to compensate for shrinkage during drops of temperature and the liquid-to-solid phase change. Polystyrene foam patterns remain in the mould and evaporate upon contact with the poured metal; wax patterns are melted out of the mould prior to the pouring of the molten metal. Metal moulds are used in that type of foundry known as die-casting. Often a hollow space is desired within the casting; in this case a core of fine sand is placed in one of the mould halves. Core boxes made of wood, metal, or resin are also used in this regard [3].

Modern foundries capable of large-scale production are characterized by a high degree of mechanization, automation, and robotics, and microprocessors allow for the accurate control of automated systems. Advances in chemical binders have resulted in stronger moulds and cores and more accurate castings. Accuracy and purity are increased in vacuum conditions, and further advances are expected from zero-gravity casting in space [4].

1.2 Sand Casting

Sand-casting is widely used for making cast-iron and steel parts of medium to large size in which surface smoothness and dimensional precision are not of primary importance. The first step in any casting operation is to form a mould that has the shape of the part to be made. In many processes, a pattern of the part is made of some material such as wood, metal, wax, or polystyrene, and refractory moulding material is formed around this. For example, in green sand-casting, sand combined with a binder such as water and clay is packed around a pattern to form the mould. The pattern is removed, and on top of the cavity is placed a similar sand mould containing a passage (called a gate) through which the metal flows into the mould. The mould is designed so that solidification of the casting begins far from the gate and advances toward it, so that molten metal in the gate can flow in to compensate for the shrinkage that accompanies solidification. Sometimes additional spaces, called risers, are added to the casting to provide reservoirs to feed this shrinkage. After solidification is complete, the sand is removed from the casting, and the gate is cut off. If cavities are intent to be left in the casting--for example, to form a hollow part--sand shapes called cores are made and suspended in the casting cavity before the metal is poured [5].

Patterns are also formed for sand-casting out of polymers that are evaporated by the molten metal. Such patterns may be injection moulded and can possess a very complex shape. The process is called full-mould or evaporative pattern casting. However, the resin sets, binding the sand particles together and forming half of a strong mould. Two halves and any desired cores are then assembled to form the mould, and this mould is backed up with moist sand for casting. Greater dimensional accuracy and a smoother surface are obtained in this process than in green (mixture of sand, clay and water) sand-casting [5].

1.3 Statement of Problem

The conventional method of casting process has little or no information of what really happen during the process. A number of test castings and re-melting is inevitable every time a new mould design is changed [2]. This method is costly and results in a lot of waste in terms of time and cost of re-melting and labour.

One way to avoid these unnecessary waste is to predict the casting process through computer simulation. Nowadays the use of solidification simulation is widely practiced in American foundries of all sizes. A recent study indicated that approximately 30% of U.S. foundries use solidification software, and all of the automotive foundries use it (Jensen, Beckermann, and Fisher 1996) [3]. Perhaps half of the castings poured in the United States today are poured in foundries that make use of solidification simulation programs. There are over a dozen commercially available simulation programs in the United States today. While in Europe, Solidification simulation is highly developed. Models have been developed in England, France, Switzerland, Germany, and the Scandinavian countries; one German model (MagmasoftTM) is commercially available worldwide and is highly regarded by many foundries. A second European model "SIMULOR," developed by Pechiney, is also in use in Europe, and some copies have been sold in the United States. SIMULOR is noted for its ease of use. Both Magmasoft and SIMULOR predict mould filling and solidification patterns for castings.

1.4 Expected Outcome

The data of the temperature history will be used to determine the appropriate time to remove the casting from the mould. More importantly, the result of this project will be used to detect mould design weaknesses that will lead to poor casting quality. This is based on the principle, which states that an alteration of mould design at the early stages will cost less compared to alteration at the later stages. [6]

1.5 Objective of Project

1) To study the heat distribution from molten aluminium alloy in two and three-gate sand mould through experiments. The experiment including pattern design and sand mould preparation until pouring molten metal and casting removal from mould. Thermocouples are placed at various critical points in the sand mould and at the mould cavity for flow detection and heat changes analysis.
2) To simulate solidification of casting process and to compare the thermal transient between the analysis model using ThermNet and the experiment data.

1.6 Scope and Limitation

In this project, two mould patterns are designed; one with two ingates and the other one with three ingates, where the differences of the thermal transient will be studied. Based on the pattern, the mould for the pattern will be prepared, as well as breaking the mould into imaginary elements which will be used to calculate the thermal characteristics in the simulation program called Thermnet. The simulation programs employ network analysis [4], which is a derivative of the finite element method. The programs have ability to model accurately the phase change process. Network approach is economical on computer effort and may be used for a first iteration in mould and die design [4].

The cast metal used for the experiment is limited to only Aluminium Alloy LM6 as thermal behavior of different cast metal is out of the coverage in this project. However, the main reason LM6 was selected is because of it high silicon content (11-13%) which greatly improves fluidity and thus castability. The important properties of the sand and aluminium alloy such as density, specific heat capacity and thermal conductivity are to be determined. These properties and some other dimensions for each element of the mould will be used by the program for simulation purpose.