Control of Cooling in Casting Dies
Based on Thermal Feedback

by

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Abstract

Thermal control of High Pressure Die Casting (HPDC) attracted significant research effort between 1970 and 2001 because of its influence on quality. Many researchers had examined feedback control and modelling of the thermal factors of high pressure die casting process in order to better regulate the process. In general, feedback and modelling had been treated as two separate areas, but the objective of this research was to investigate them as a whole. The research work here is funded by the Cooperative Research Centre (CRC) for CAST and is part of a larger program involving Deakin University, CSIRO, Ford and Nissan Australia. The research is specifically aimed at high pressure die casting processes but analogous processes (such as injection moulding and thixomoulding) that used cooling channels to stabilise or balance die temperature profiles could also benefit from this research. A key element of this research program was the development and construction of a small, prototype casting system that could be used to explore the validity of any developed, thermal models.

1. Introduction

The objective of this research is to investigate the possibility of stabilising the temperature in a casting die by establishing a closed loop control, based upon thermal feedback and modelling.

The research work involves a casting process known as high pressure die casting (HPDC). At its most basic level, a casting process is based upon molten metal being poured into a cavity (which had been formed into the desired shape) and allowing it to cool to a solid. The surrounding construction, to make the cavity, known as the casting die, is generally also constructed of metal. The main aim of the die is to control the delivery of the molten metal to the final shape cavity and to hold it in place until the metal solidified. The general concept of casting had been in existence for centuries and the HPDC process had been in existence for over 150 years. Doehler (1951) noted that some inventors began patenting their machines around 1850 (e.g., Sturges in 1849 and Barr in 1852) with the simple concept of forcing molten metal into a die cavity. The HPDC machine with which this research was involved was referred to as a "cold chamber" machine which is shown schematically in Figure 1.

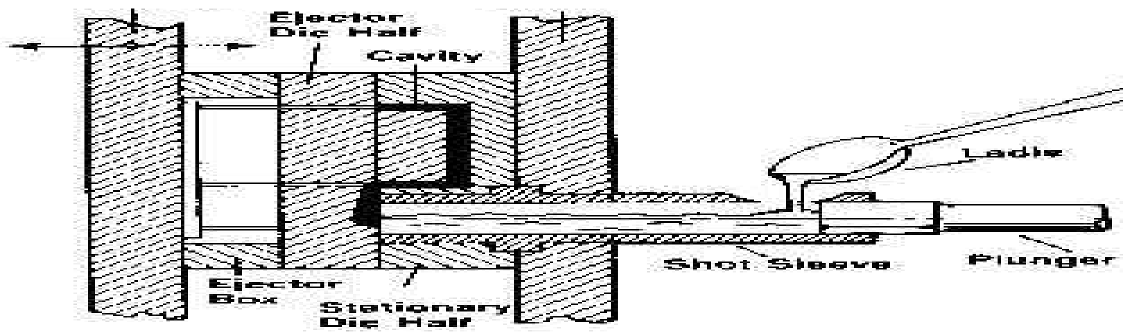

Figure 1 - Schematic Diagram of a Cold Chamber Machine (after Bever 1986 Vol. 2 p.1145).

In examining the overall process, it became evident that a drawback to having molten metal being forced into a die was the creation of turbulent fluid flow into the die. This could result in casting problems, such as blow holes[1] and porosity[2] (Degarmo, Black, Kohser 1988). As a result of these problems, a final casting's subsequent processing (to obtain a desired geometry or mechanical properties) was sometimes limited (Campbell 1991).

Temperature was another important feature in the HPDC process because it influenced fluid flow (Street, Watters and Vennard 1996) and the transfer of heat[3] from the cast metal. Self-evidently, transfer of heat (energy) from the cast metal to its surroundings had to occur in order for the solidification process to take place. Some of the three heat transfer modes, in a typical HPDC process, are shown in Figure 2.

[1] Blow holes defined by North American Die Casting Association (NADCA) (1998, p.10): *Voids or holes in a casting that may occur due to entrapped air or shrinkage during solidification of heavy sections*.
[2] Porosity as defined by NADCA (1998, p.72): Voids or pores, commonly resulting from solidification shrinkage, air trapped in a casting or hydrogen exuded during electroplating
[3] Heat as defined by Cengel (1998, p.4): is a form of energy that can be transferred from one system to another as a result of temperature.

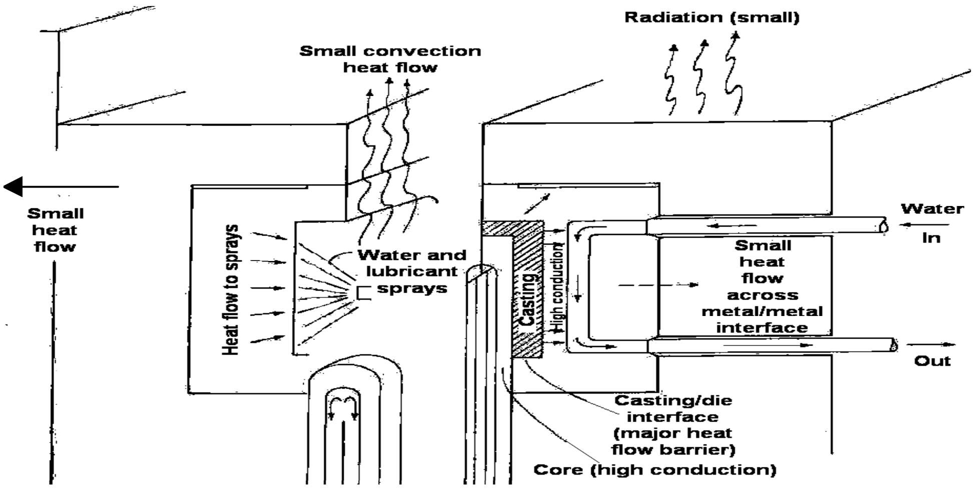

Figure 2- The three modes of heat transfer in a high pressure die casting process(after ASM (1988, p.293)).

Heat transfer was a major factor in high pressure die casting process because the solidification time could be dependent upon the heat transfer (Poirier and Poirier, 1992). The mechanical properties of a finished casting could be related to the microstructure obtained from the casting process but were also dependent on temperature and time (Callister, 1991). Some of the microstructural growth patterns, which could occur in a casting process, can be seen in Figure 3. These schematic diagrams highlight the different microstructures that could form from a metal alloy because of this solidification process.

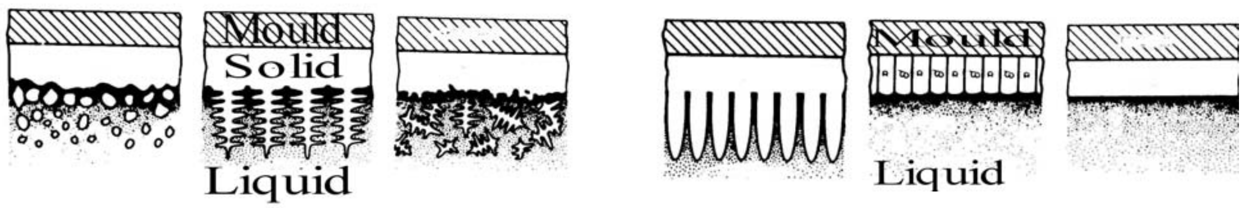

Figure 3 - Shows some of the Microstructure Growth Sequences (after Bever 1986 Vol.1 p.537)

This research program was part of a larger CRC CAST research program whose objective was to reduce the cycle time for aluminium HPDC process while maintaining the quality of the components. The cycle time could be reduced through a reduction of each constituent process time, but if this approach did not take into account the quality of the components then the reduction would be offset by an increase in defective components and would not necessarily provide an economical benefit.

The main concern with reduced cycle times, in the HPDC process, was the increase in heat input into the system. If the heat output from the system did not change to compensate for the heat input, then the overall die temperature would increase. An increase in die temperature did not always affect the quality of the cast components because the die temperature range for good quality castings was relatively large (Street 1986). However, "*soldering of the tool* [die] *and blistering and distortion of the casting*" could occur if the die temperature was too high (Street 1986, p.333). If the die temperature was too low then the result could be "*casting*[s] *having a poor surface finish and ultimately leads to misruns*" (Street 1986, p.333).

Some of the techniques that were used to control parts of the pressure die casting process are shown in Figure 2. The two main mechanisms, as highlighted in Figure 2, were cooling channels (usually drilled holes throughout the die where coolant fluid was circulated) and external die sprays (usually a combination of lubricants and water) that occurred between casting cycles.

Following on from the above described background, the principal objective of this research was to investigate the possibility of stabilising the temperature profile in a casting die, through a numerical methods temperature profile input but within the cycle time of the casting process.

2. Industrial Implications

As highlighted in the Introduction, the temperature of the die is a key factor in the production of quality castings and maintenance of die quality. The outcomes of this research program could contribute towards improved productivity in terms of HPDC (i.e., reduction in cycle time) and/or improvement in cast component quality. These outcomes may also have applications in other areas where cooling of dies is an issue (e.g., injection moulding and thixomoulding).

3. Literature Review

The control of heat transfer by the use of cooling channels had been documented since the 1970s (Kiser, Sanders, and Frost 1972) and, in 1970, researchers (Booth 1970) had used basic feedback control techniques. The control methods were improved over the decades, with more recent work being undertaken by Bishenden and Bhola (1999). These researchers varied the flow rate through the cooling channels to achieve a desired temperature in segregated sections of the die. The control process incorporated thermocouples to measure the die sections and a proportional integral differential (PID) control algorithm to vary the flow rate through the cooling channels.

Research had also been conducted in the use of mathematical models in association with control techniques to control the solidification or heating of metals to obtain desired mechanical or physical properties. One of the more common processes that used mathematical modelling and control techniques to control the solidification was spray cooling, such as Samaras and Simaan (1997) and Hall and Mudawar (1995).

4. Research Program

The research program consists of the development of a new strategy that could enable temperature profiles, generated from a numerical methods technique, to be integrated into a real time control system. The existing strategy, known as the inverse numerical methods technique, could take a few minutes to a few hours to obtain temperature profiles for a heat transfer problem. A brief summary of the inverse numerical methods technique and the new strategy is shown in Figures 4 & 5. It is predicted that the new strategy could obtain temperature profiles of the heat transfer problem in high pressure die casting and implement a control technique within the typical cycle time of 60 – 100 seconds.

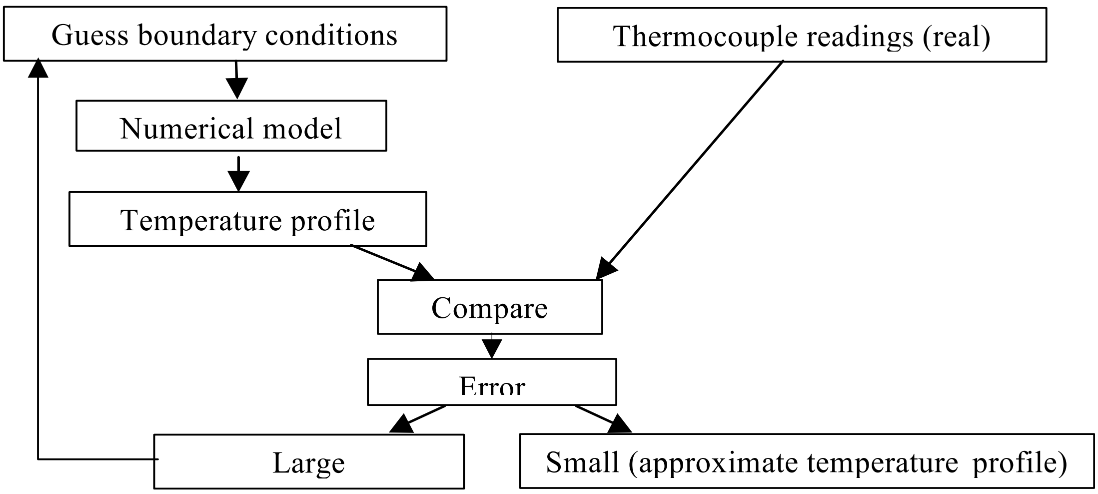

Figure 4 – A typical inverse numerical methods strategy to determine the temperature profiles in a heat transfer problem

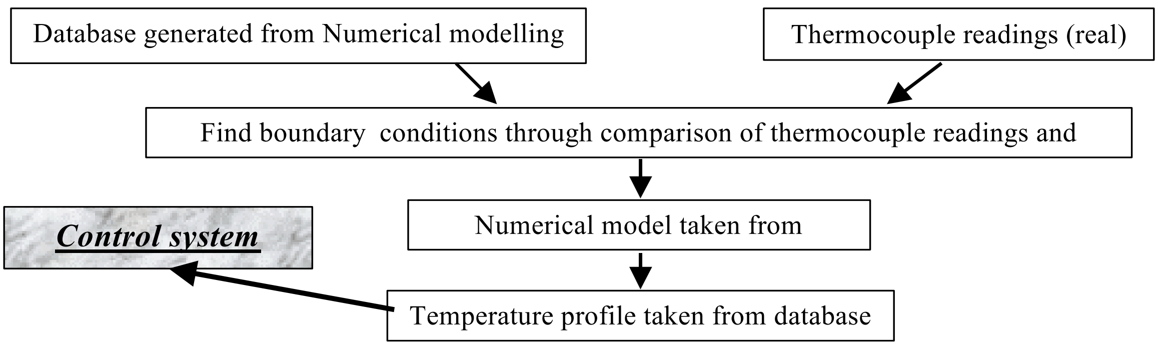

Figure 5 – A new strategy to determine the temperature profiles in a heat transfer problem so a control system could utilise the data.

5. Experimental Test Rig

An experimental test rig was specifically developed for this research, rather than utilising a commercial HPDC machine because the rig was considered to be more flexible in terms of control of specific variables in relation to the cooling channels. It was also impractical to use a high-cost production machine for such experimental research.

The experimental test rig was a variation of a previous test rig developed from projects through the cooperation of CSIRO, Ford and Nissan (c1996-1999). An improvement to previous designs included a controlled heat source. A brief summary of some key components in the experimental test rig are, as follows:

- The approximate die block dimensions were taken from a section of a commercial HPDC die with modifications to the cooling channels to simulate some of the cooling patterns in the die.
- The heat source, which was composed of gas burners.
- The PLC controlled the timing sequence and movement of the burners and spray gun to represent the heating (solidification) and cooling (external cooling from the spray cycle) from a typical commercial HPDC process.

6. Summary

This research program is still within its early stages and hence no significant conclusions can be drawn at this time. Hence, this paper has been limited to a general discussion on the die construction, fluid dynamics, heat transfer and solidification issues that had to be considered in the context of the proposed research. In summary, the objective of the ongoing research is to use numerical methods to predict the temperature distribution within a high pressure casting die, and to use this as feedback for a closed loop control system. This will be investigated through construction of a prototype equipment.

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