

The Impact of Die Start-Up Procedure for High Pressure Die Casting

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ABSTRACT

Die pre-heating has a beneficial effect on die life, by reducing thermal shock and stress fluctuations on the die surface. The findings from this paper indicate that the die surface stress decreased by 44% when the die is pre-heated to 150°C, and decreases by 57% when the die is pre-heated to 200°C, in comparison to when the die is started "cold" with an initial temperature of 20°C.

Changes to the die start-up procedure, by switching off the die internal water cooling for the first four casting cycles, results in the die heating to operating temperature in fewer casting cycles, resulting in fewer castings being scrapped before the die achieves steady state operating temperature. From this, a saving of four castings per start-up can be made, reducing scrap by 4.5%, leading to lower manufacturing costs, reduced energy usage and increased useful die life. The modified die start-up procedure had a negligible effect on the die surface stress fluctuation, with a beneficial reduction in scrap.

The process improvements which were run to improve die life, show that by modifying the die start-up procedure, the scrap rate can be reduced making the process more profitable.

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INTRODUCTION

High pressure die casting 'HPDC' is a casting process widely used to manufacture non-ferrous castings for the automotive industry.

With HPDC molten metal is forced into the die cavity under pressure. Due to the high speed of metal filling and rapid solidification rate, this casting process is commonly used to manufacture high volume, thin walled castings rather than using other die casting methods, such as gravity or low pressure. Non-ferrous alloys, mainly aluminium, magnesium and zinc are most commonly cast using this process.

Figure 1 shows a section view of a HPDC die. HPDC is ideal for high volume thin walled castings due to the fast cycle times, typically measured in seconds depending on the casting size and wall thickness.

HPDC accounts for almost 70% of aluminium components manufactured today [1]. Many aluminium components for the automotive industry are cast using this method, due to the high productivity and near net shape production. Large components such as gearbox housings and engine blocks are typical examples where casting weight can

be in excess of 15 kg. Due to the short cycle times, the die is exposed to high temperature fluctuations each and every casting cycle, resulting in steep thermal gradients on and below the surface of the die [2].

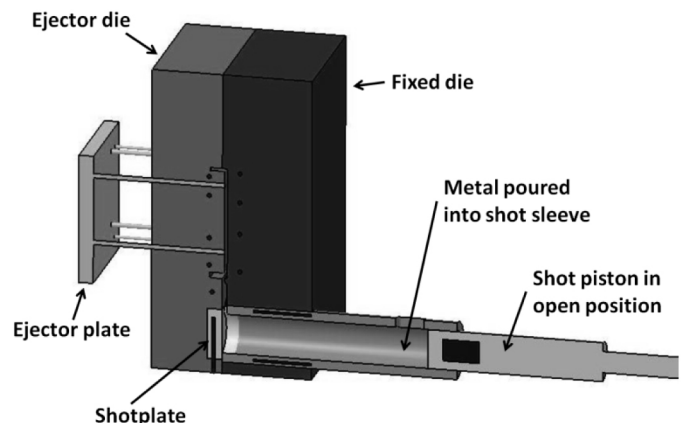


Figure 1. Illustration of a cold chamber high pressure casting die.

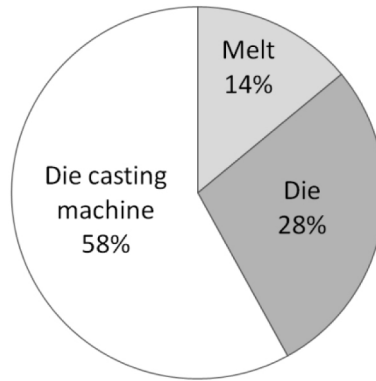


Figure 2. Cost breakdown of manufacturing a casting.

Die Temperature

The die surface is rapidly heated by the molten aluminium being injection into the die cavity. The heat is carried away from the die by an internal water cooling system causing the casting to solidify. After solidification the casting is ejected and then removed from the die. The die surface is further cooled by a die-lube spray (a mix of oil and water), used to both lubricate and cool the surface of the die. For HPDC there is no insulating diecoat layer between the casting and the die, which is commonly used for gravity and low pressure permanent mould casting. Therefore, the molten aluminium makes direct contact with the die surface, encouraging a fast solidification time due to the high heat transfer coefficient between the die surface and the casting [3, 4, 5]. As there is little insulation between the die surface and the molten metal, the heat transfer coefficient between the die and the casting, along with the peak die surface temperature, are greater for HPDC than seen with other casting methods. Therefore, the die experiences more extreme and sudden temperature changes compared to other die casting processes.

Thermal Shock

When thermal stress is generated by a sudden change in temperature, the process is referred to as 'Thermal shock' [6].

With HPDC, the die experiences sudden changes in surface temperature when the molten aluminium makes contact with the die surface and is then cooled with die lube. The stress resulting from thermal shock is usually greater than that due to slow heating and cooling due to the steeper temperature gradients which are induced. A distinction between thermal stress and thermal shock is that with thermal shock, the rate of application of the resulting stress is very rapid.

Collin and Rowcliffe. [7] reported that materials which are used in high temperature applications are often exposed to rapid thermal changes which cause thermal stresses and are at risk of thermal shock damage. They concluded that the crack growth vs. temperature difference curves show no crack growth at very low ΔT s, stable crack growth at medium ΔT s

and unstable crack growth above a certain ΔT , depending on the material properties.

Moon et al. [8] reported that good ductility and toughness as well as high tensile strength at elevated temperatures are important properties for increased thermal shock resistance and that the measured thermal shock resistance confirms that hot work tool steels are favoured by their ability to accommodate both elastic and plastic deformation before fracture at elevated temperatures.

Price. [9] reported that thermal shock cracking tends to start at geometrical discontinuities such as corners due to the increased stress concentration. An increase in sample quench time was seen to accelerate the rate of crack growth, indicating that as the temperature fluctuation increases, so does the crack growth. Price further reported that most cracks stop at less than 3 mm, with the most severe stopping at a depth of 6.2 mm after experiencing a peak temperature of 400°C however, the number of cycles for this testing is not stated.

Tab. [10] reported that lower carbon steels can provide greater thermal shock resistance, when compared to higher carbon steels and that the cracks in the higher carbon steel (0.9%C) are more than three times the depth of those for the lower carbon steel (0.4%C). His work shows that the grade of steel should be carefully selected for its chosen application. As AISI H11 and AISI H13 tool steels have approximately (0.4%C) they are well suited for high thermal shock conditions such as HPDC.

The Casting Die

Due to the operating conditions used for HPDC, the die experiences very harsh conditions, with high speed metal fills, resulting in fast fill times along with extreme temperature and stress fluctuation on and just below the die surface.

Figure 2 shows the three main costs associated with the manufacture of a HPDC component. It can be seen that the casting machine accounts for more than half the costs, therefore, reductions in cycle time and scrap rate will give beneficial savings in reducing the casting cost price.



Figure 3. Image of heat check cracking on the surface of a die.

The important material properties required for HPDC dies are resistance, to thermal shock and to softening at elevated temperatures [11]. The longevity of the die is directly related to the casting temperature of the molten metal, thermal gradients in the die and the exposure frequency to the high metal temperature [12]. Due to the repeated temperature fluctuations on the die, it must be dimensionally stable, have high hot yield strength, good resistance to high temperature softening and good thermal conductivity [13].

The die is the most critical component for the HPDC process, as the die forms the casting which is then sold to the customer. As the die is heated by the molten aluminium and then cooled by the internal water cooling system and die lube, extreme temperature and stress fluctuations arise on the die surface which can result in surface cracking, known as heat check cracking (Figure 3).

Pries et al. [14] reported that the die is one of the main expenses for the aluminium die caster and that the life is limited to 100,000 castings due to heat check cracking. They reported several factors which have a detrimental effect on the die and which lead to heat check cracking. The quality and properties of the tool steels used, are vital to ensure good heat check cracking resistance. However, due to the processing of the die steel by machining and by spark erosion, very high tensile residual stresses can develop on the surface if the die is not correctly stress relieved.

Material properties

The extent of thermal shock in service, is of extreme importance and is most intense on the die surface. The cyclic behaviour of heating and cooling has the effect of expanding and contracting the die surface. Deformation is the primary stage of thermal shock damage and cracks are the second stage which represents the major resulting damage to the die surface [13]. To withstand these extreme loads, the die material must be very ductile through the entire temperature range encountered in service. Otherwise the surface of the tooling will develop heat check cracks.

Lee. [15] reported that higher thermal conductivity of the die material will reduce cycle time, due to the better rate of

heat removal from the casting. The main mechanical properties which affect the thermal fatigue resistance of the steel are: the Young's modulus and strength. Some metallic materials such as cast iron but especially ceramic materials are more susceptible to failure when thermally shocked, due to their high value of Young's modulus and coefficient of thermal expansion, with low strength and thermal conductivity [16]. The ideal die material would have a low Young's modulus with high yield strength, however, the best combination of properties are high hot strength and ductility. High strength is associated with low ductility therefore it is difficult to attain both characteristics within the same material. Hot hardness is critical, as at high temperatures the die surface loses strength and hardness. This reduction will result in lower thermal fatigue resistance and a shorter die life.

Gorbach et al. [17] reported on tests from different types of hot work tool steels, that higher resistance to thermal fatigue is due to higher ductile characteristics. Therefore, the resistance to thermal fatigue in tension depends to a greater extent on the ductility than the strength when selecting a suitable die material. However, the mechanical and thermal properties of the die material will change over time [18].

Objective

It has been shown that die temperature fluctuation has a profound effect on the rate of heat check cracking and in turn die life [19], therefore two trials were run to monitor die surface temperature under different scenarios.

The die pre-heating investigation studied the effects of pre-heating on the die, this was run because many foundries pre-heat their dies prior to casting and to determine the impact of die pre-heating to the thermal shock on the die surface during the initial casting cycles.

The die start-up trial (without die pre-heating) was run by switching the internal water cooling off for the first four casting cycles, so that the die could attain operating temperature quicker than the conventional method where the internal water cooling is run continuously.

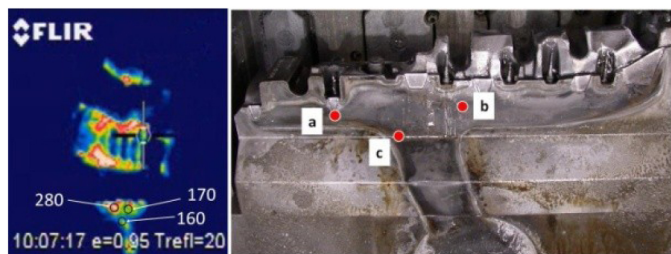


Figure 4. Image of the trial die slide core showing the position of the measurement points on the thermal image, taken when the die was running in production from an angle of approximately 40° to the die face. The photograph on the right shows the location of the three measurement point on the actual die [12].

EXPERIMENTAL METHOD

Die Pre-Heating Investigation

To minimise thermal shock on the surface of the die, many foundries pre-heat their dies prior to casting runs. This is achieved either by gas flame on the die surface, radiant heat from gas, electrical resistance heaters, or by internal oil heating circuits. All of these methods heat the die to so-called operating temperature, typically 150-260°C [20]. The die is pre-heated to reduce the thermal shock when the molten aluminium is injected into the die cavity. However, many foundries do not pre-heat their dies prior to casting.

To determine the benefits / disadvantages of pre-heating the die, three casting simulations were performed using Magmasoft® [21]. These simulations considered an initial cold die temperature of 20°C and two dies initially pre-heated to 150°C and 200°C.

Die Start-Up Trials

As an alternative to physically heating the die, a strategy was tested whereby normal operating temperature conditions were established more quickly.

To attain a stable die operating temperature in fewer casting cycles, the internal die cooling water was simply turned off for the first four cycles so that the die heated up in a shorter period of time. This required no modifications to the die and was achieved by reprogramming the logic of the die casting machine.

To compare the die start-up, with and without the internal water cooling running, a comparison was made between the “standard start-up” (std) and the “modified start-up” (mod) procedure.

Three points on the slide core, as shown in Figure 4, were monitored throughout the casting cycle so that a temperature measurement could be made at the three points. From this temperature measurement the resulting stress / strain could be determined.

In order to record the die surface temperature during the casting cycle a Flir™ E2 thermal imaging camera was connected to a laptop computer via a USB video capture device, (EasyCAP Capture ‘DC60’). This enabled thermal

images to be captured and recorded as a video file, giving a record of the die surface temperature when the die was open.

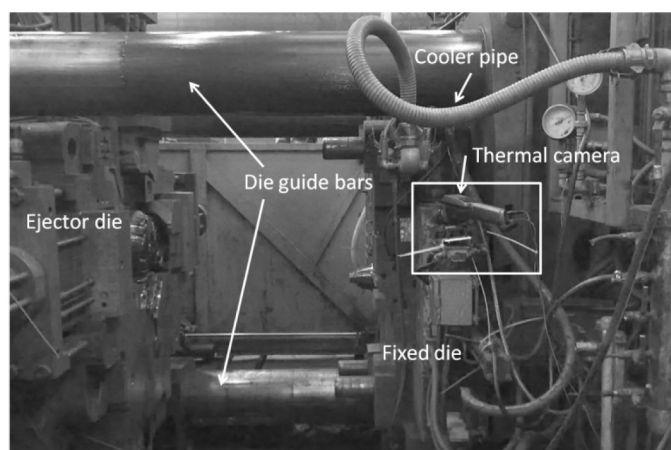


Figure 5. Image showing the location of the Flir™ E2 thermal camera, within the white box and its location in relation to the die and casting machine [12].

The thermal camera was securely attached to the fixed half of the die so that images of the ejector half of the die could be recorded (Figure 5). Due to die lube spray and conditions within the die casting cell, cables were run to a laptop outside the cell where the trial data could be viewed and recorded.

A simple Magmasoft® model was used to determine the die surface temperature when the die was closed, as described in section (Simple Magmasoft® model) when combined with the temperature trace taken from the thermal camera results, as described in section (Thermal image of the die surface). These two methods were used to define the die surface temperature throughout the complete casting cycle. The temperature traces for the selected points on the die surface were then recorded, from which stress /strain curves were generated using the method described in section (Simple FE analysis to determine stress /strain from temperature).