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Predicting die life from die temperature for high pressure dies casting aluminium alloy

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A B S T R A C T

The objective of this research was to determine the surface temperature of a high pressure die casting die during casting conditions. This was achieved by instrumentation of an insert which was placed in the shotplate region of the die. This research overcame the challenge of directly measuring the die surface temperature during a HPDC production casting cycle and shows that this is an effective method to determine the die surface temperature during the casting cycle. The instrumentation results gave a peak and minimum temperature of 500 °C and 240 °C respectively during steady state running conditions with a molten aluminium casting temperature of 660 °C. Stress analysis from the steady state measured temperature of the die surface was calculated through a simple FEA model and the resulting stress fluctuation was applied to a fatigue equation for the die material, the predicted number of cycles for cracking to start was found to correlate well with observed die damage.

1. Introduction

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

With HPDC the molten metal is forced into the die cavity under pressure. Typified by high filling speeds and rapid solidification rates, this casting process can produce shapes which are more detailed than components manufactured using gravity or low pressure die casting methods.

Non-ferrous alloys, mainly aluminium, magnesium and zinc are most commonly cast using this process. HPDC is ideal for high volume thin walled castings due to the fast cycle times, ranging from seconds to several minutes depending on casting size and wall thickness, therefore enabling production in excess of 60 castings per hour from one casting machine.

The important material properties required for HPDC dies are, resistance to thermal shock and to softening at elevated temperatures [1]. The most commonly used die materials are H11 and H13 hot work tool steels. 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. 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 [2,3].

HPDC accounts for almost 70% of aluminium components manufactured today [4]. 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. The HPDC process involves rapid temperature fluctuations on the surface of the die, resulting in steep thermal gradients on and below the die surface [5]. It is very difficult to measure the die surface temperature throughout the casting cycle due to the difficulty of instrumentation on the surface of the die.

1.1. Die temperature

With HPDC, the die surface is rapidly heated when the molten aluminium is injection into the die cavity. After the casting solidifies, it is ejected and then removed from the die. The die surface is then cooled by the die-lube spray (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 more direct

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contact with the die surface, encouraging a fast solidification time due to the high heat transfer coefficient between the die surface and the casting [6–8]. As there is little insulation between the die surface and the molten metal, the heat transfer coefficient between the die and casting along with the peak die surface temperature are much greater than seen with other casting methods.

Norwood et al. [9] reported, through instrumentation measurements with thermocouples and temperature paints that the surface temperature of the die reached between 400 °C and 450 °C approximately one second after metal injection and that the die cooled to between 150 °C and 200 °C due to the die spray, giving a temperature change of approximately 250 °C throughout the casting cycle.

Srivastava et al. [10] reported that for a typical thermal cycle during the operation of an aluminium HPDC die, the surface of the die reaches a peak temperature of 457 °C and decrease to a minimum of 107 °C, giving a temperature fluctuation of 350 °C within 20 s.

Venkatasamy [11] measured die surface temperatures ranging from 500 °C to 120 °C when a melt temperature of 660 °C was used for casting. Research has shown that as molten aluminium contacts the die surface, a thin layer freezes almost instantaneously and as a consequence, the die never reaches the temperature of the molten metal [12].

The average die running temperature is in the region of 200 °C to 300 °C and during each casting cycle the die surface temperature fluctuates from approximately 100 °C to 500 °C, resulting in cyclic high stress fluctuations, leading to heat check cracking [13]. Heat check cracking is a result of thermal fatigue and is the main life limiting factor for the die associated with HPDC [14]. From more accurate measurement of the die surface temperature, the temperature fluctuations can be used to determine the stress fluctuation on the die surface. The stress fluctuations can then be applied to a fatigue prediction model, the results of which can be compared to actual die surface damage.

2. Experimental

2.1. Removable shotplate insert

In order to better determine the surface temperature of the die during the casting cycle, a replaceable insert was designed which could be removed without causing too much disruption to production. This insert was located in the shotplate,[1] as this is the region of the die which experiences the greatest temperature fluctuation and peak temperature during the casting cycle. Also by positioning the insert in this location, there was no impact on the casting and the die could run in production without affecting the quality of the product.

The inserts, shown in Fig. 1, were machined from Böhler W302 [15] grade H13 tool steel, 45 HRC and were held in place by a cotter pin which passes through the centre. The sides of the cylindrical insert have a 5° draft, and the overall dimensions are as follows, *H* 48.5 mm, max ∅39.09 mm and min ∅30.6 mm.

The inserts were manufactured slightly too tall, so that excess material could be removed by surface grinding until the inserts were ≈0.05 mm above the shotplate surface. The height difference was kept to a minimum to ensure that the insert did not foul on the cast runner when the slide opened.

[1] The shotplate is the die insert that faces the shot tube (where the metal enters the die). It is this part of the die first exposed to the injected aluminium alloy and its function is to direct the metal flow into the runner system. It is the most severely stressed part of the die and is frequently replaced.

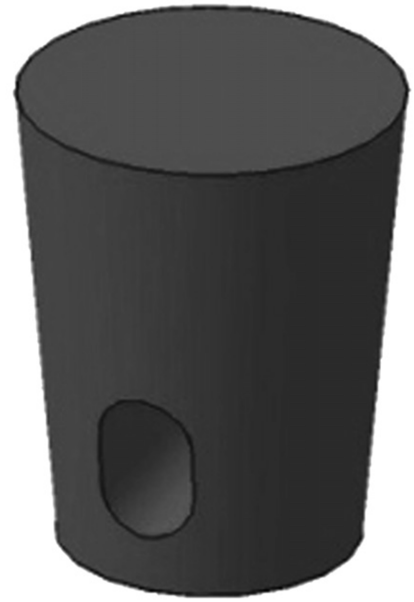

Fig. 1. Image of the removable shotplate insert.

Fig. 2 shows the location of the shotplate insert relative to the runner on slide 3. Slide 3 provides side details on the casting and forms one boundary surface for the runner system. When the molten metal is injected into the die it will flow through the runner system and therefore causes this part of the die to experience some of the highest temperature fluctuations.

Fig. 3 shows a photograph of the shotplate insert fitted to the shotplate. The outline of the runner system can also be seen. This would not be apparent on a new shotplate; it is a consequence of the scouring caused by the flowing metal over several thousand casting cycles.

Fig. 4 shows a sectioned view through the slide 3 assembly. This also gives the three main steps required in order to remove the shotplate insert.

Step 1 Remove the outer cover plate, by removing the M5 cap head screw holding it in place. This cover plate is put in place to ensure that if the cotter pin works loose, it will not fall out and be squashed between the die halves, causing damage.

Step 2 Cotter pin is removed by screwing a slide hammer into the cotter pin's M12 tapped hole, and tapping out the cotter pin.

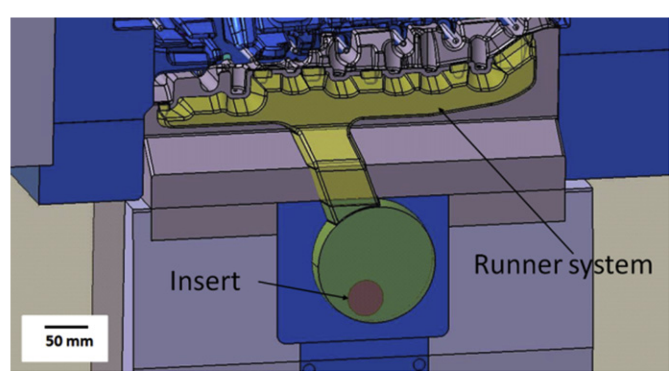

Fig. 2. Images showing the position of the runner system relative to the shotplate insert on slide 3.