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Development of a method for assessing erosive wear damage on dies used in aluminium casting

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ABSTRACT

During pressure die casting of aluminium, molten/semi-solid droplets of aluminium come into contact with the die surface. A number of damage mechanisms can occur as a result of this event, some related to thermal effects and some mechanical effects such as erosion. Dies are very expensive to manufacture and options for improving die life would be beneficial.

Very few test methods exist to study the damage mechanisms and for trialling new materials/coatings. Most studies have involved either casting actual components or placing material specimens in a die casting machine so that they are impacted by the aluminium. This is very time consuming and expensive.

In this work a laboratory test was developed specifically to study the erosion effects of the aluminium particles. A mounting frame was utilised to hold both flat and cylindrical specimens made from H13 steel (typically used for die manufacture). The frame was placed in a shot blaster which was used to fire aluminium balls (3 mm diameter—based on aluminium droplet size calculations) at the specimens. Different velocities were used and the flow was pulsed to mimic successive castings being made.

Flat specimens were tested at different angles and cylindrical specimens were tested central to the flow of aluminium and in an eccentric position to cover a range of possible aluminium/die impact scenarios. Optical microscopy and roughness measurements were used to characterise the wear on the specimens. Wear rates were also determined. Behaviour was compared with data from the literature where available. Wear damage was also compared with worn dies. High speed videoing was also used to study the impact behaviour of the aluminium balls.

It was concluded that the test method was a suitable approach to use in identifying potential solutions that could extend die life. In future work the effects of temperature and application of coatings will be explored.

1. Introduction

Die casting is a high volume production process in which molten metal is forced into a die under pressure. There are many advantages to using this manufacturing approach [1]. Excellent dimensional accuracy and surface finishes can be can be achieved without any machining except to remove flash around the edges and drill/tap holes. Very complex shapes can be made and hollow sections and internal cavities can be included. Fine grain structures and good mechanical properties can also be realised.

The process is fast and economical compared to other techniques for manufacturing metal components such as forging or rolling [2]. Die casting is particularly appropriate when a large quantity of small to medium sized parts is needed with good detail and dimensional consistency and a fine surface quality [3]. The down sides are that there are long lead times due to die manufacture, large parts and high melting point materials cannot be accommodated and if parameters are not optimised there can be problems with porosity.

Most castings are made from non-ferrous materials, but ferrous materials can also be cast. In this work the focus is on high pressure casting of aluminium.

1.1. Aluminium die casting process

There are a number of methods available for casting including hot and cold chamber, with and without the use of high pressure. Here high pressure, cold chamber casting of aluminium is considered. A typical layout for a cold chamber machine is shown in Fig. 1 [1].

The molten metal is taken from an external furnace and is poured into a shot sleeve. A plunger then pushes the metal through a runner and gate into the die cavity under high pressure. This usually happens in three phases. In the first the plunger moves at

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low speed to push air out of the sleeve, the speed then rises to get the metal to fill the runner system and finally high speed is used as the metal is entering the die cavity. It is very important these phases are well controlled as entrapped air can lead to porosity in the castings. The high pressure used ensures that proper fill occurs and minimises shrinkage. The casting is left to solidify before the die is opened and the part removed and the process starts again.

Casting techniques are developing continuously, largely in order to achieve greater control over the main variables such as the metal used, inlet temperatures, pressures used and shot speed in order to improve throughput and avoid problems such as porosity [4].

1.2. Dies

For every component to be manufactured a new die must be made. This is an expensive process (typically tens of thousands of pounds) and represents a large investment for a casting company. As a result the dies must last for a long time and maintain high component quality. The die design is complex as it must be made in two parts to allow separation after the process is complete to allow removal of the casting. Good flow of the metal must be ensured and dimensional allowance for shrinkage etc. must be built in. The die also has to be able to endure harsh operating conditions. The molten metal is injected under pressure at high temperature (the melting point of aluminium for example is 700 °C) which occurs in cycles. Dies are usually made from H13 steel which has the right mix of good machinability, strength and resistance to thermal fatigue and erosion, its properties are listed in Table 1.

Die life is affected by a number of degradation mechanisms: thermal fatigue (as a result of the temperature cycles); erosion; erosion–corrosion; chemical attack and soldering [5]. All result from the contact of the molten metal with the die surface. In this study the main focus was on erosion due to the impact of molten or semi-

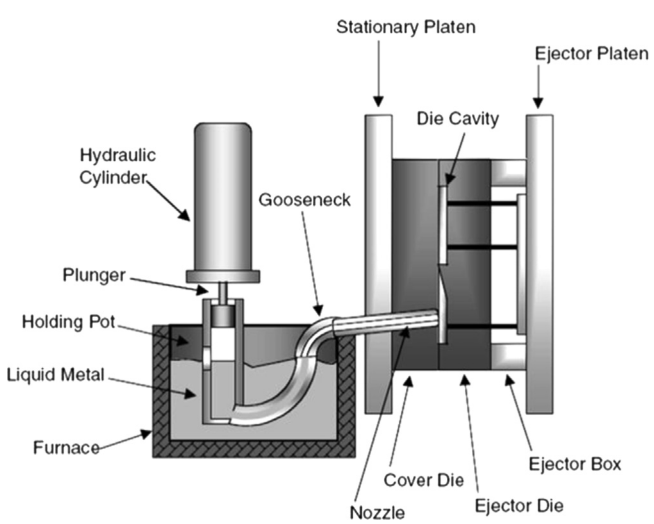

Fig. 1. Schematic of a cold-chamber casting machine [1].

Table 1
Properties of H13 steel.

Property	Value
Tensile strength (MPa)	1650
Elongation at break	9%
Poisson's ratio	0.3
Hardness (H_V)	300–400
Modulus of elasticity (GPa)	210

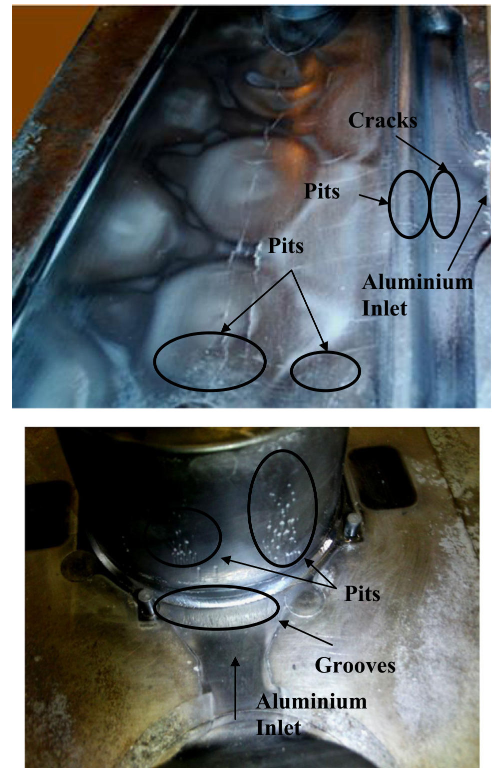

Fig. 2. Damage due to erosion and thermal fatigue.

solid metal droplets on the die as the metal is forced into the die under high pressure. The results of both thermal fatigue (cracking) and erosion (pits/gouges) are visible on the images shown in Fig. 2 of used dies. While erosion may be the most significant cause of failure, mechanisms coexist and interact and often evidence will be found of several on a die surface [6]. As can be seen the metal droplets are impacting a variety of surface geometries which will have a large effect on the surface damage that results.

1.3. Previous die test methods

Despite the investment made in dies, less attention has been paid to the development of solutions to reduce the impact of the failure mechanisms than has been placed on process control. The work that has been carried out has used a range of techniques across different levels of complexity, largely to assess the application of coatings to the dies or surface hardening. In order to assess the effect of coating the dies many tests have been carried out using scratch testing techniques [7–10]. These tests are easy and quick to carry out and can provide a good way of ranking coating/treatment performance; however, they do not represent the actual test conditions or failure mechanisms, so are actually quite limited.

An erosive test has been run based on ASTM standard G76-95 [11]. However, the erodent used was silica which is quite angular in nature and would give different behaviour to aluminium droplets. A different “erosive” approach has been used which involves rotating specimens at high speed (800 rpm) in molten aluminium [10]. However, as before, this is not representative of the situation in the actual die where molten/semi-solid droplets are impacting the surfaces.

In order to expose potential solutions to actual operating conditions, a test was developed that allowed a holder with multiple treated/coated pins to be placed in an actual casting machine [12]. Testing has also been carried out using actual dies which are sectioned and examined after use in a casting machine. While these methods enable testing in an actual casting environment, they are costly and very time consuming. Apart from the specimen manufacture, it will