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Investigation of erosive-corrosive wear in the low pressure die casting of aluminum A356

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Abstract

Die surfaces are exposed to a wide range of operating conditions during permanent mould casting. The combination of materials, temperature, pressure, and flow can result in erosive-corrosive wear. The resulting accelerated wear can be a recurring problem along the sprue exit surface during the low pressure die casting of aluminum A356 wheels. The primary factor determining the occurrence of wear in wheel model-sprue combinations was sprue geometry, which led to the study of the influence of flow behaviour on erosive-corrosive wear. Laboratory erosive-corrosive wear experiments were performed by immersing and rotating test pins in liquid aluminum A356 under different test conditions. In addition to round cross-section pins, profiled cross-section pins were used to study the influence of flow on wear behaviour. Flow simulations were developed to predict the flow of liquid aluminum both within the sprue during die filling and around the rotating profiled cross-section pins. It was found that less wear occurred along the trailing edge of the profiled cross-section pins where flow was directed away from the pin surface. Increasing the pin draft angle or test rotation rate increased this effect and decreased the amount of wear occurring along this edge. This partially explains why accelerated wear is a problem for low exit angle sprues, but does not explain why some sprue geometries were more prone to accelerated wear on the surface preceding the constriction point.
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Keywords: Liquid aluminum A356; Die casting; Sprue; Erosive-corrosive wear; Rotating pin test

1. Introduction

Die casting is a high volume manufacturing process capable of producing complex non-ferrous parts with good surface finish at low scrap rates [1]. The low pressure die casting (LPDC) technique is a die casting variant commonly used in the production of rotationally symmetric parts, such as wheels, where surface finish is critical. The main components of a LPDC machine setup for wheel casting include the holding furnace, joint pipe, and die (sprue plate and wheel mould), illustrated in Fig. 1. During casting, pressure is applied to the top surface of the liquid metal in the holding furnace, pushing liquid metal up the joint pipe and into the die cavity. Pressure is applied in a series of stages to fill the joint pipe, sprue, and wheel mould. The joint pipe is connected to the sprue which channels liquid metal into the wheel mould. Mould coatings are applied to the inside sprue surface prior to each casting run to prevent contact with liquid aluminum. Damage or removal of this coating exposes the sprue surface to liquid aluminum and can lead to erosive-corrosive wear, which limits sprue life and increases maintenance costs.

Sprues at a North American wheel foundry are made from 4140 steel (composition provided in Table 1) and have typical lifetimes of around 1000 shots. However, select sprues require repair or replacement after as few as 300 shots. At the initiation of this study, there were six LPDC wheel model-sprue combinations used in production at the foundry, two of which consistently had problems with accelerated wear. Each sprue is unique to a wheel model, resulting in a wide range of sprue diameters and lengths. With only one exception, accelerated wear was reported on sprues with small exit diameter and exit angle. Accelerated wear was observed to occur along the surface following the constriction point (illustrated in Fig. 2), referred to as the exit surface.

Wheels at the North American foundry observed during this study are produced from aluminum alloy A356 (Al–7Si–0.3Mg). Liquid aluminum is injected into the sprue at 700 ± 10 °C. The casting cycle is approximately 300 s and pressure in the holding furnace is ramped according to a pressure curve. The timing of

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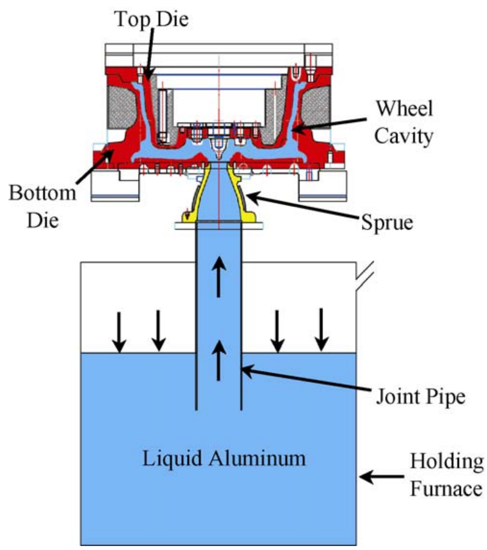

Fig. 1. Illustration of the low pressure die casting process.

Table 1
Chemistry of pin materials and aluminum melt alloy (wt%)

Element	AISI 4140 [2]	AISI H13 [3]	Ti–6Al–4V [4]	A356 [5]
Cr	0.80–1.10	4.75–5.50	–	–
Mn	0.75–1.00	0.20–0.50	–	<0.1
C	0.38–0.43	0.32–0.45	–	–
Si	0.20–0.35	0.80–1.20	–	6.5–7.5
Mo	0.15–0.25	1.10–1.75	–	–
W	–	–	–	–
V	–	0.80–1.20	4	–
Ni	–	<0.30	–	–
Mg	–	–	–	0.25–0.45
Fe	Balance	Balance	0.13	<0.2
Ti	–	–	Balance	<0.2
Cu	–	–	–	<0.2
Al	–	–	6	Balance

the pressure curve is tailored to the sprue and wheel cavity geometry to ensure complete filling. As stated earlier, accelerated sprue wear is a recurring problem for some wheel model-sprue combinations and, given that there are few major process differences aside from sprue geometry, the problem appears to be related to flow. Given the corrosive nature of liquid aluminum and the motion of the liquid during filling, erosive-corrosive wear driven by flow was investigated.

2. Background

While this study focused on sprue wear, erosive-corrosive wear is a common problem in aluminum die casting. The exposure of die surfaces to liquid aluminum can lead to significant material loss resulting from erosion-corrosion or erosive-corrosive wear. Erosion-corrosion is a form of accelerated corrosion where the resulting damage is much greater than that from either erosion or corrosion alone. In die casting, a protective coating is applied to die surfaces to prevent liquid aluminum from contacting the die surface. As long as this coating is intact, corrosion reactions such as dissolution and intermetallic compound

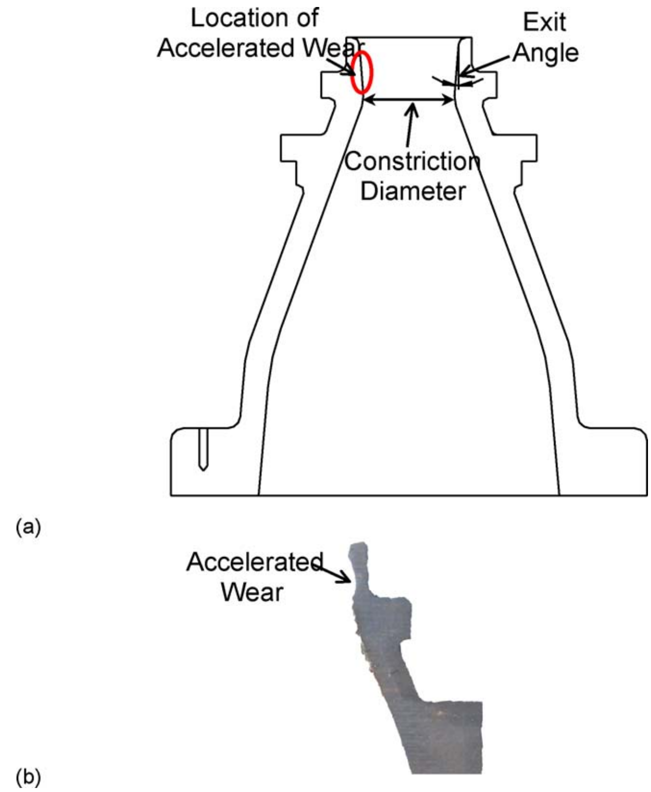

Fig. 2. Cross-section of a sprue is shown in (a) with a worn exit surface in (b).

formation cannot occur. However, the motion of the liquid metal can damage or remove this coating, and once this occurs, corrosion processes will proceed. In aluminum die casting, material loss is not so much a result of the mechanical wear of solid surfaces (erosion) as it is the removal of surface layers (coating and intermetallic compounds) and the acceleration of the dissolution reaction [6]. When surface layers are removed, the solid surface is again directly exposed to the liquid aluminum and more intermetallic compounds form. This accelerated corrosion process, referred to as erosion-corrosion, occurs repeatedly and can result in significant material removal.

Reviewing the available literature, wear during aluminum die casting has been investigated through laboratory pin immersion tests [7–10], sometimes referred to as dip tests. These tests have also been referred to as accelerated corrosion tests because the test environment is more extreme than that in the actual casting process. Melt temperatures are usually higher than the liquid metal temperature experienced by most die locations during casting. Cycle times are short in die casting, however, in pin immersion tests exposure times are usually on the order of hours to ensure that a quantifiable amount of wear occurs. In these tests, pins are either immersed or rotated in a liquid aluminum melt at various melt temperatures and exposure times. Other test parameters can include rotation rate, melt composition, pin material and surface treatment. Test pins usually have round cross-sections and are made from the same steel alloys as those used for dies. In the literature describing these tests, pins have been tested individually by rotating them about their long axis or in multi-pin set-ups where a specimen holder is

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