Engineering Failure Analysis 33 (2013) 457–464

Contents lists available at SciVerse ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Erosion process analysis of die-casting inserts for magnesium alloy components

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ARTICLE INFO

Article history:
Received 12 March 2013
Received in revised form 20 May 2013
Accepted 20 June 2013
Available online 2 July 2013

Keywords:
Die-casting die
Erosion
Magnesium alloy
Failure analysis

ABSTRACT

Erosion of die materials during die filling has long been regarded as possible damage mechanism of dies in high-pressure die casting (HPDC) of magnesium alloys. Melt impingement and erosion have also been proposed as important steps leading to die washout. However, little information on direct measurements of any type of die insert erosion in HPDC is available. The present analysis shows the insert surface states and chemical compositions of a failed die obtained from a die casting plant. Results show the presence of numerous microholes, microcavities and cracks on die surface. The diameter of the smaller microholes is about 9 μm, whilst that of the larger microholes is over 100 μm. Mechanisms causing insert erosion are discussed. Erosion takes place through depression, plastic deformation and tearing actions resulting from both impact pressure and high-velocity lateral jets. These damage mechanisms create pits on the surface of eroded samples.

1. Introduction

Magnesium alloys have received extensive recognition because of their light weight, high strength/weight ratio, high thermal conductivity and good electromagnetic shielding characteristics, amongst others [1–3]. They are used widely in the automobile, aeronautical and aerospace and electronics industries [4]. Compared with sand casting, in high-pressure die casting (HPDC), the metal is injected into the die at high velocity and solidifies under applied pressure. This process enables the production of intricate components at relatively low cost and high production rates [5]. Die-casting dies have attracted constant attention from engineers because of their die life, which is a major consideration in die casting process, dies may cost more than the die casting machine depending on the complexity of the part being produced. However, these dies are prone to erosion, corrosion and thermal fatigue failures when used for extended periods of time during the die casting process [6], leading to a decline in production efficiency and an increase in the cost of parts being produced. More importantly, some scraps from failed die-casting dies may be entrapped in the castings and consequently decrease the corrosion resistance of the casting. Thus, with the continued development of die casting industry, more consideration is being given to die failure analysis of notable decreases in efficiency and productivity of the die casting process.

Die failure modes in die casting may be classified as heat checking, gross cracking, erosion and chemical attack, including corrosion and soldering. Previous studies have focused mainly on heat checking [7–10]. HPDC experiments to investigate erosion in die materials in HPDC experiments were recently conducted by Venkatesan, Shivpuri and their colleagues

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1350-6307/$ - see front matter
http://dx.doi.org/10.1016/j.engfailanal.2013.06.018

[11–17]. The researchers proposed that erosion is primarily caused by the impact of solidified particles present in the melt during filling but did not present sufficient evidence to illustrate the nature of die erosion in HPDC. Studies on wear and failure mechanisms using controlled experiments and computer simulations have been performed, and experimental results have indicated that metal velocity is the primary mechanism for die washout [18]. However, inserts are the most important operating components of HPDC systems and account for a large portion of the entire design procedure of dies. The complexity, cost and durability of a progressive die, as well as the accuracy of metal stamping products [19], depend largely on the inserts. Unfortunately, whole some investigations on the erosion of hot work tools used in other nonferrous material die casting have been conducted, few systematic studies on the erosion of magnesium alloy die-casting dies can be found in recent literature.

The aims of our on-going research are to understand the corrosion process of a failed magnesium alloy die-casting insert in a cold chamber machine under high-speed liquid impact and to offer experimental data that may be used to determine effective ways of reducing corrosion. Understanding erosion in die materials, as well as the influence of erosion on the formation of the soldering layer, is thus necessary. In the current paper, existing data and theories on erosion are analysed.

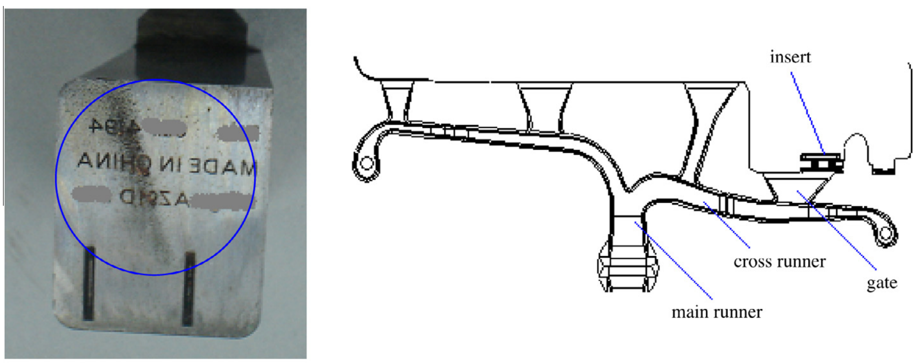
2. Materials and methods

A failed die obtained from a die casting plant was used to analyse the characteristics of die erosion and washout regions. This die is used to produce magnesium notebook computer components. Service conditions of the die are as follows: die casting material, AZ91D; molten magnesium alloy temperature, 610–650 °C; injection pressure, 40 MPa; die preheat temperature, 280–300 °C; die holding time, 6–8 s.

Fig. 1a shows the morphology of eroded insert close to the centre of the gate of the movable die. The dimensions of the eroded surface are 25.9 mm × 31.6 mm, and the moulding position of the product is shown in Fig. 1b. The insert is located near the gate to deliver molten metal passing through the mould to all sections of the mould cavity. On the surface of the failed insert, a fan-shaped erosion trail with the centre of the gate as the centre of a circle may be observed. Erosion begins beyond a radius of 10 mm and is generally radial in appearance. The degree of erosion varied with the distance from the centre of the gate, and the eroded appearance occurred to badly, then slightly again with increase of the radius.

The insert was made from SKD-61 hot work tool steel, which is frequently used in tools. The steel is similar in chemical composition to H13 hot work tool steel found in the U.S.A. The die was quenched in oil at 1030 °C after being held for 1.5 h. During heating, it was kept for 1 h at 550 °C and 850 °C to ensure temperature uniformity in the insert and then tempered twice at 550 °C. Some samples from different positions of the insert eroded. The surface and the heart of the die were cut to determine their chemical composition and hardness using a spark source atomic emission spectrometer (SPECTRUM MAX-x, Germany) and a Rockwell hardness tester, respectively.

The morphology of the eroded surface was observed by scanning electron microscopy (SEM). The specimen used for metallurgical microscopic observations was etched with 4% nitric acid. Specimens for transmission electron microscopy (TEM) analysis were prepared as follows. First, a specimen with dimensions of about 10 mm × 10 mm × 1 mm was sliced from the eroded surface. Then, the specimen was mechanically polished to about 40 μm and cut into discs 3 mm in diameter. The specimens were polished again to less than 20 μm in thickness. Finally, the specimens were electro-polished with 5% perchloric acid and 95% ethanol solution in volume and analysed using the transmission electron microscope (H-800) equipped with a double-tilt stage. Hardness was measured using a Rockwell hardness indenter with a load of 150 kg and a loading time of 15 s. For each sample, at least five points were measured in a regular grid pattern with spacing of ~8 mm between measurements to obtain an average value.



(a) (b)

Fig. 1. (a) surface morphology of the eroded insert, the elliptical shows the corrosive area, and (b) sketch of the insert position corresponding to the product.