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IMPACT AND ENERGY DISSIPATION CHARACTERISTICS OF SQUEEZE AND DIE CAST MAGNESIUM ALLOY AM60

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Abstract

High-pressure die cast (HPDC) magnesium alloy AM60 is recognized for its versatility in the manufacturing of weight sensitive components of relatively thin cross section. To further expand practical applications of the alloy, squeeze casting has been proposed to allow for thicker castings. In this study, AM60 alloy specimens of 10mm thickness were squeeze cast using a hydraulic press with an applied pressure of 60 MPa. Fracture energies, following a Charpy Impact Testing protocol, of the squeeze cast specimens were characterized in comparison with the HPDC counterparts using both experimental and numerical techniques. The experimental results show the squeeze cast alloy absorbing approximately 46.2% more energy during impact than its HPDC counterpart. Scanning electron microscopy fractography reveals the favourable quasi-cleavage fracture mode of the squeeze cast alloy AM60, relative to the decohesive rupture fracture mode present in the die cast alloy.

Introduction

Weight reduction is a driving factor in the transportation sector, where fuel efficiency is paramount in the success of any commercial vehicle design. As such, the development and application of magnesium alloys has seen rapid growth, due to the high specific strength of the alloys, and their excellent die castability [1]. Despite the advances in magnesium alloys, the casting of body-on-frame magnesium alloy components has been restricted to thin-walled applications due to the high porosity and coarse microstructure associated with the die casting of relatively thick components [2]. However, past research has indicated that squeeze casting of magnesium alloys provides a means of casting relatively thick components, while maintaining a fine microstructure with low levels of porosity [2].

Squeeze casting is a process that involves the solidification of molten metal by making use of very large filling gates and imposed high pressures. The high applied pressures keep entrapped gases in solution and squeeze the molten metal from hot spots to incipient shrinkage pores. As a result, the porosity in a squeeze cast component is almost completely eliminated, with an accompanying increase in densification. Furthermore, the elimination of the air gap at the liquid-mould enhances heat transfer, resulting in enhances solidification and cooling rates. Thus, the squeeze casting process promotes improved mechanical, thermal, and microstructural properties, due to grain refinement and porosity reduction within the cast component [2-5].

Previous research has focused on the microstructural behaviour and tensile properties of squeeze cast magnesium alloys as a function of section thickness and casting method. The objective of this study was to determine the impact resistance and fracture behaviour of the alloy for a relatively thick specimen, using both casting methods, and to establish a numerical model which accurately predicts the energy absorbed until failure by each specimen during Charpy Impact Testing. This paper presents the results of instrumented Charpy Impact testing, numerical modeling of the Charpy Impact event, and SEM fractography of the fracture specimens.

Experimental Procedure

<u>Alloy Preparation</u>

The Magnesium alloy selected for this study is the conventional magnesium alloy AM60, of which the chemical composition is listed in Table 1. Cylindrical coupons with a diameter of 95mm and section thickness of 10mm were squeeze cast. The squeeze casting processes began with the transfer of the molten alloy (690°C) into the bottom half of a preheated (275°C) die set mounted in a hydraulic	Al (wt.%)	Mn (wt.%)	Zn (wt.%)	Ni (wt.%)

press. The dies were then closed, with the top half lowering into the bottom die. A steadily increasing pressure was applied to the melt by the bottom half of the die by means of a piston until a pressure of 60 MPa was achieved. This pressure was held until the entire casting had solidified. For the purpose of this study, flat rectangular coupons (125mm x 27mm) with a section thickness of 10 mm were cast in a 700 ton cold chamber horizontal high pressure die casting machine.Alloy Symbol				
AM60A	5.89	0.335	0.0068	0.0004

Squeeze and die cast castings were cut for density measurement, porosity evaluation, Charpy Impact testing and the subsequent SEM fractography analysis.

Porosity Evaluation

Porosity of the coupons was evaluated via density measurement. Following the measurement of specimen weight in the air and distilled water, the actual density (D_a) of each specimen was determined using Archimedes principle based on ASTM standard D3800 [6]:

$$D_a = W_a D_w/(W_a - W_w) \quad [1]$$

where W_a and W_w are the weight of the specimens in air and in water, respectively, and D_w is the density of water. The porosity of each specimen was calculated by the following equation:

$$\%Porosity = [(D_t - D_a)/D_t] \times 100\% \quad [2]$$

where D_t is the theoretical density of the alloy AM60, which is 1.8g/cm^3).

Instrumented Charpy Impact Testing

The relative fracture energies of the squeeze and die cast alloy were obtained using a Riehle Impact Testing Machine that has been calibrated and instrumented following ASTM standards E23 [7] and E2298 [8]. Charpy specimens were sectioned from the center of each casting with dimensions of 10mm x 10mm x 55mm and were tested in the unnotched condition. Tests were performed at room temperature to obtain the load/displacement behaviour of the specimens during impact. Absorbed impact energies were subsequently calculated, and the average of six tests was taken for each casting condition.

Fractography Analysis

For the fracture analysis, the fracture surfaces of specimens that had undergone Charpy Impact testing were viewed under low and high magnifications of a JSM-5800LV scanning electron microscope (SEM). Areas of ductile and brittle failure were subsequently noted and correlated with previously calculated porosity measurements.

Results and Discussion

Porosity Evaluation

Figure 1 presents the porosity and density measurements taken of the AM60 series alloy for the squeeze and die cast conditions, with a casting thickness of 10mm. As can be seen, the squeeze cast sample has only 0.72% porosity, while the die cast sample has 4.00% porosity. This corresponds to a decrease in porosity of 81.8% relative to the die cast sample. Furthermore, there is a 5.16% increase in density of the squeeze cast sample relative to the die cast sample, due to the reduction in porosity. The porosity reduction and accompanying densification of the squeeze cast AM60 alloy can be attributed to the fact that the applied pressure suppresses gas nucleation, while enabling the melt to penetrate areas of microshrinkage forming in the last solidifying region of the casting.

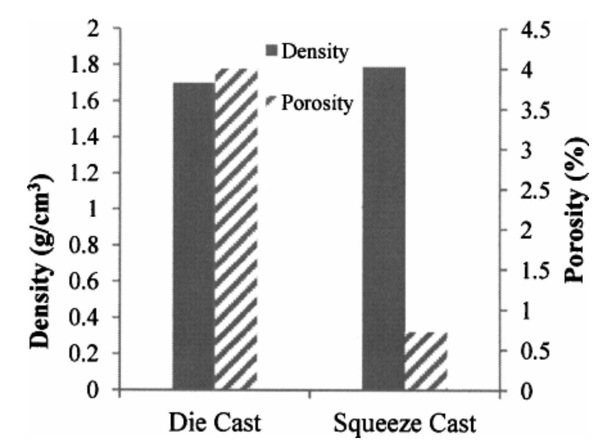


Figure 1: Effect of casting method on density and porosity of AM60.

Instrumented Charpy Impact Testing

Figure 2 shows the absorbed fracture energies of the AM60 alloy after undergoing impact to failure using a Charpy Impact testing machine. From these results, it is apparent that the squeeze cast alloy requires more energy for failure to occur, with the squeeze cast alloy requiring 46.2% more energy relative to the die cast alloy. These results indicate that AM60 cast using the squeeze casting process, for a casting thickness of 10mm, has a greater resistance to high impact loadings relative to the die cast alloy, and is thus more ductile. This finding may be directly attributable to the fact that the squeeze cast specimens had significantly less porosity with respect to the die cast specimens.

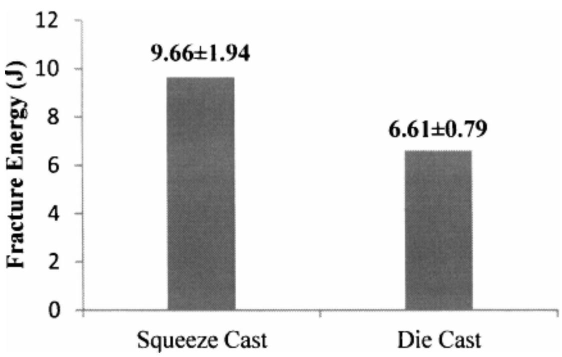
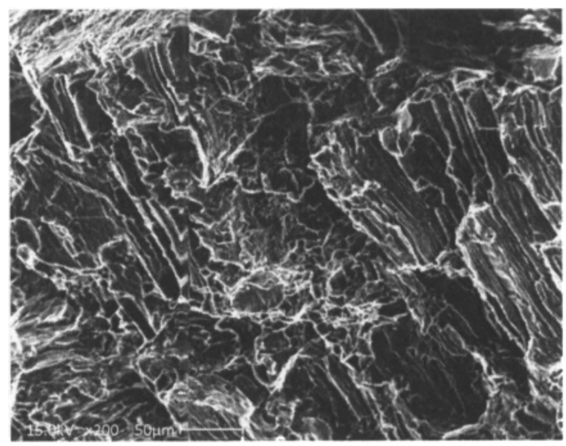


Figure 2: Absorbed energy to failure under Charpy Impact loading of 10mm thickness squeeze and die cast AM60 alloy.

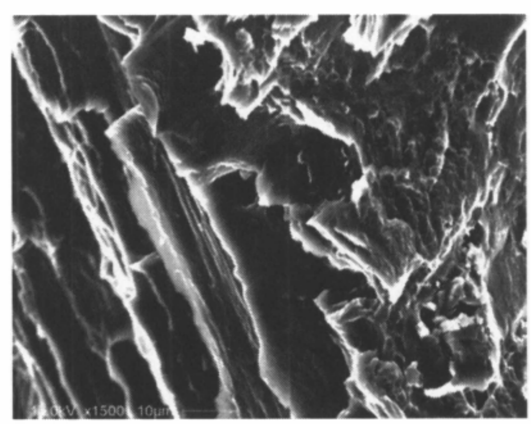
Fractography Analysis

Differences in the fracture behaviour of the die cast and squeeze cast 10mm thickness AM60 alloy are clearly revealed in Figures 3 and 4 by SEM fractography. Figure 3 shows the typical fracture surface that was observed of the squeeze cast alloy. As can be seen from Figure 3(a), the fracture surface contains many flat facets, which are characteristic of the quasi-cleavage fracture mode. The flat facets are accompanied by steps and river markings. The steps are the result of the cleavage propagation interacting with dislocation tangles or twins, while the river markings are attributable to shear connections forming from steps created along grain boundaries with non-zero twist components. Therefore, the formation of river markings is the primary indicator that some plastic deformation has occurred in the squeeze cast alloy prior to failure, which correlates well with the previously discussed absorbed energies during Charpy Impact testing. Also note that the river markings move from right to left, which corresponds to the deformation induced from the Charpy Impact striker. The fractograph with higher magnification, Figure 3(b), better shows the depth of the steps and river markings, which further demonstrate that plastic deformation occurred in the fracture specimen of the squeeze cast alloy.

Figure 4 shows the typical fracture behaviour that was observed after Charpy Impact testing of the 10mm die cast AM60 alloy specimens. Converse to the squeeze cast alloy, the die cast alloy exhibits a fracture mode most consistent with decohesive rupture. This is illustrated in Figure 4(a). There exist a number of sites where intergranular fracture is present. The cause for this mode of fracture may be attributed to the porosity present within the die cast specimen, which causes low cohesion between grains, thus providing an ideal location for crack initiation. Figure 4(b) provides a higher magnification fractograph that is in good agreement with the conclusions drawn from Figure 4(a). However, in the higher magnification fractograph there exists a small amount of cleavage in the top right corner of the image, indicative that some plastic deformation may still occur in regions of lower porosity. Regardless, the results of SEM fractography for both casting methods are in good agreement with the results obtained from Charpy Impact testing.

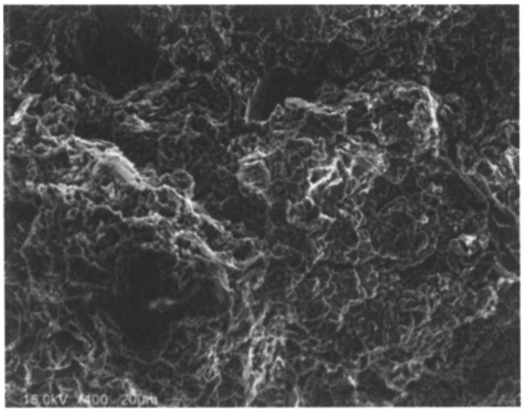


(a)

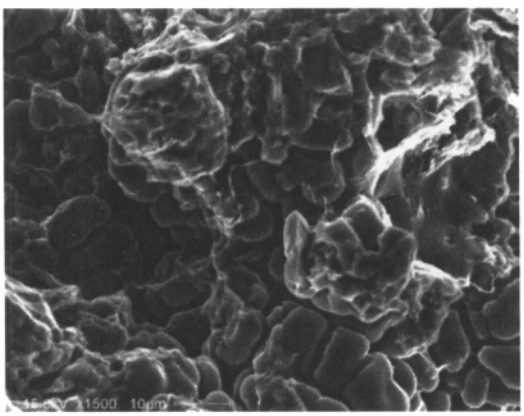


(b)

Figure 3: SEM fractographs of squeeze cast Mg alloy AM60 with a 10mm cast thickness after undergoing Charpy Impact testing, (a) low magnification and (b) high magnification.



(a)



(b)

Figure 3: SEM fractographs of the die cast alloy after Charpy Impact testing (a) low magnification and (b) high magnification.

Conclusions

The effect of the casting process was investigated on the fracture mechanics of Magnesium alloy AM60. The results of Charpy impact testing and SEM fractography indicate that for a relatively thick casting, squeeze casting promotes ductile fracture characteristics and an increase in absorbed energy to fracture. The reduction in porosity and accompanying material densification should be responsible for the improved fracture properties of the squeeze cast alloy.

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