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Hot tearing of Thin-walled Al-Mg Alloy in die-casting

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Hot tearing of thin-walled Al-Mg alloy in die-casting was studied. Computational solidification simulation by using MAGMAsoft was conducted to set up the die-casting and melt conditions. The results showed that Al-Mg alloy was had a higher residual stress and distortion generated after solidification than Al-Si alloy. Because of these residual stress and distortion, defects were evident in Al-Mg alloy at the predicted area by simulation while there was no visible defect observed in Al-Si alloy. Therefore, it was suggested that adequate die temperature and casting process optimization to control the above defects of Al-Mg alloy.

Keywords: *Die-casting, simulation, ALDC12, ALDC6, solidification, residual stress, Tatur test.*

1. Introduction

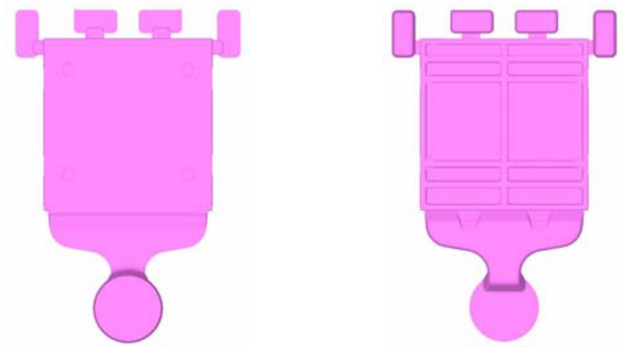
Recently, demand for the lightweight alloy in electric/electronic housings has been greatly increased. However, among the lightweight alloys, aluminum alloy thin-wall die-casting is problematic because of its insufficient fluidity and feedability to fill the thin cavity [1, 2]. The most widely used aluminum die-casting alloys are Si based alloy with as high as 22%Si. However, these Al-Si alloys generally have very low in ductility to be applicable to an impact resistance component, such as endplate for Ni-MH battery. Therefore, Al-Mg alloys are attractive for fabricating the body parts because of their high ductility without heat treatment. However, it is known that the Al-Mg alloy (ALDC6) die-castings often show higher susceptibility to cracking as they solidify than conventional Al-Si alloy (ALDC12) die-castings. Such cracking occurs at high temperatures during solidification often at hot spots where the casting solidifies last.

In this study, hot tearing of thin-walled aluminum component was examined experimentally with Al-Mg alloy. Furthermore, computational solidification simulation was also conducted.

2. Experimental details

2.1 Numerical simulation

Computational solidification simulation by using MAGMAsoft was conducted to set up the die-casting and melt conditions. The software is based on the finite volume method (FVM), which couples both the widely used Navier-Stokes and Fourier equations. The solidification simulation is able to calculate the mold filling, solidification and the development of residual stresses caused during the casting process. As such, it is therefore believed to have a high accuracy by considering the heat loss during the mould filling stage [3, 4]. The initial conditions and process parameters and the chemical compositions of casting alloy for this study are described in Table 1. ALDC12, ALDC6 and STD61 die steel were used for the simulation. Also, the initial temperature of the melt was 730℃. Plunger diameter and active sleeve length were 60mm and 490mm, respectively. Figure 1 showed designed thin walled component in size of 115×145mm with thickness of 3 and 5mm (rib area). The total number of elements used for simulation was 20 million.



(a) Front side view (b) Rear side view

Fig. 1. Schematic illustration of die-casting components.

Table 1. Condition for computer simulation.

Classification		Condition
Material	Cavity	ALDC12, ALDC6
	Fixed die	STD61
	Moving die	STD61
Initial temperature	Cavity	730℃
	Die	150℃
Machine type	Buhler 53D	
Tip diameter	60mm	
Slow shot velocity	0.35m/s	
Fast shot velocity	3.5m/s	
Length of shot sleeve	490mm	
Switch over stage 1-2	415mm	

2.2 The Tatur test

The Tatur test was conducted to observe the shrinkage characteristics of the aluminum alloys. The dimension of the Tatur steel mold was described in Figure 2. The temperature of the molten alloy and the Tatur mold were controlled to 750℃ and 250℃ prior to pouring, respectively.

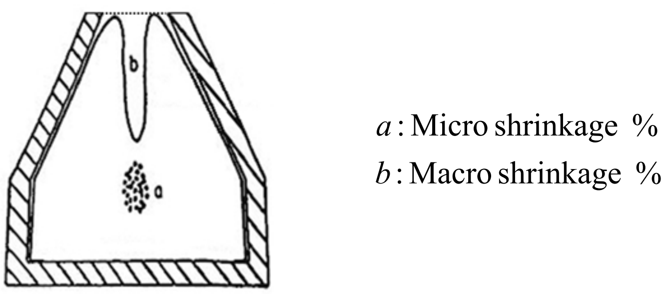


Fig. 2. The schematic of Tatur test mold.

2.3 Actual die-casting conditions

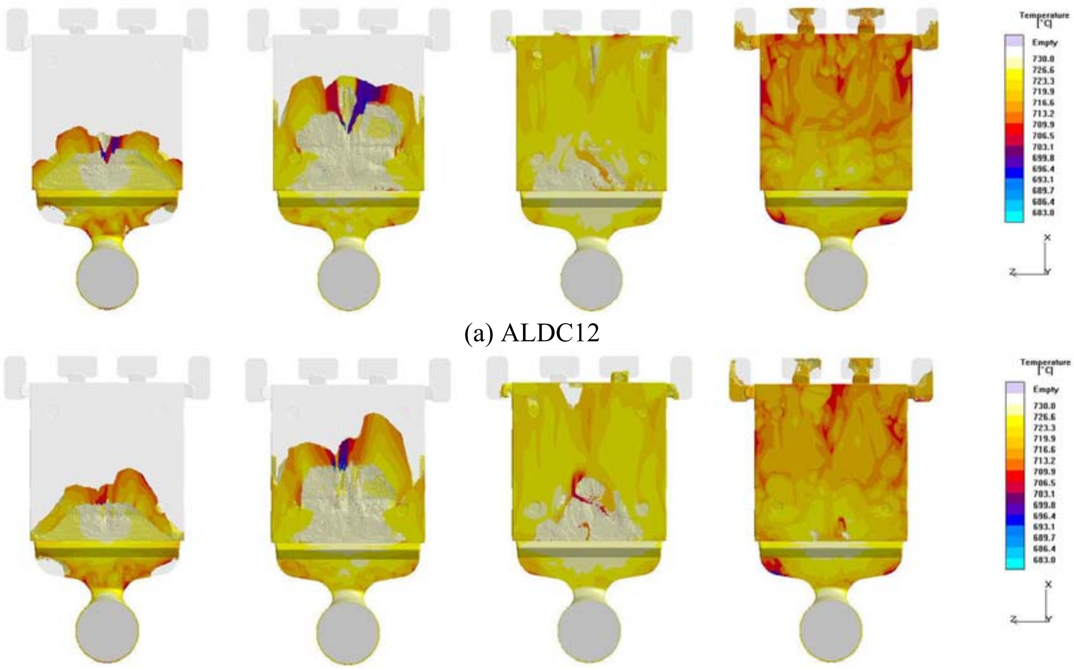
For the comparison with results of computational solidification simulation and actual casting, ALDC6 and ALDC12 alloy were cast by using a high speed die-casting machine. A commercial ALDC6 (Al-3%Mg alloy) and ALDC12 (Al-11%Si-2.5%Cu alloy) aluminum die-casting alloy was used. Total 1,540g of the molten metal was laded at the temperature of 730℃ and the die temperature was maintained at 150℃. Die-casting conditions were summarized in Table 1. Molten aluminum alloy was injected into the die cavity under the conditions of 0.35m/sec in injection speed until the plunger traveled up to 415mm in shot sleeve and then the injection speed was accelerated linearly to the high injection speed of 3.5mm/sec from 415mm to 490mm in shot sleeve.

The simulation was also compared with the actual experiment with the same conditions above. Die-casting machine, Buhler Evolution B 53D was used for the experiment.

3. Results and discussion

3.1 Results of temperature distribution

Generally, the casting characteristics of Al-Mg based alloys are quite lower than that of Al-Si based alloy which include fluidity, feedability and die soldering. However, the filling pattern of the both ALDC6 and ALDC12 alloys were found to be very similar. As shown in Figure 3, melt flow at the center area of the component was delayed and filled at the last state of filling. As a result, there was very high in possibility to have casting defects, such as porosity, shrinkage and misrun, and surface defect, at the last filled region.



(a) ALDC12

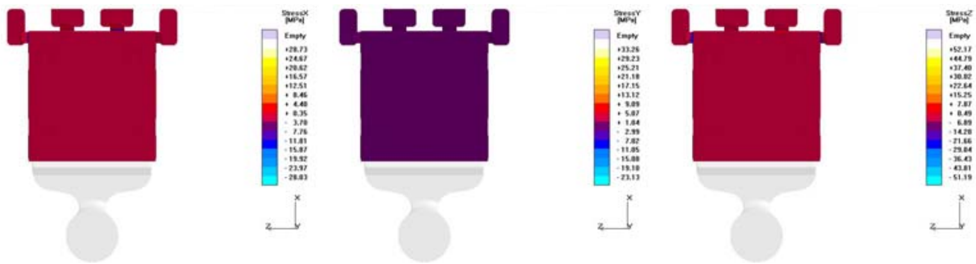
(b) ALDC6

Fig. 3. Simulation results of filling temperature distribution

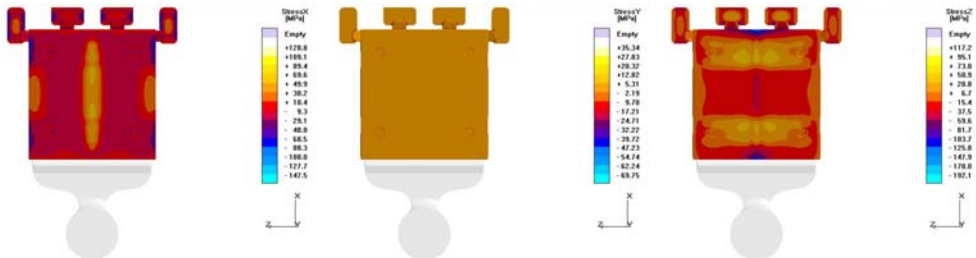
3.2 Residual stress

The stress was also simulated and the result was displayed in Figure 4. As shown, ALDC6 alloy exhibited relatively very high stress concentrated regions, especially near the area with rib.

The actual die-casting experiments were conducted and the results were shown in Figure 5. Because of the difference in casting characteristics, defects were evident in ALDC6 alloy at the predicted area by simulation while there was no visible defect observed in ALDC12 alloy. Therefore, it was suggested that varying the compositions of alloying elements, especially Si and Mg, adequate die temperature and casting process optimization to control the above defects of ALDC6 alloy.



(a) ALDC12



(b) ALDC6

Fig. 4. Simulation result of stress.

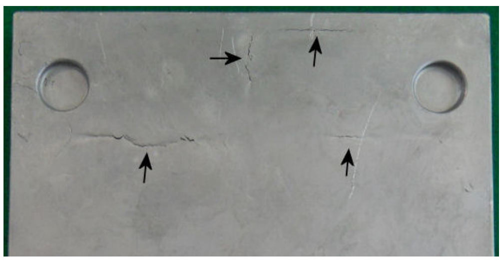
	Die-casting components	Near Overflow
(a) ALDC12		
(b) ALDC6		

Fig. 5. Thin-walled endplate cast in ALDC12 and ALDC6; Arrows were indicated the cracks.

3.3 The Tatur test result

The pipe volume represents the amount of shrinkage in the Tatur test. Because of the cone shaped mold, the molten metal was continuously fed from the top to the middle of the casting, which was the last solidification region, and generates the pipe, which was considered as the total amount of macroshrinkage in the alloy. The results of the Tatur test casting were shown in Figure 6. Hot tearing or hot cracking generally occurs during solidification of casting and welding because of a loss of strength and ductility, resulting from the thermal stress and the presence of intergranular liquid films [6-11].

(a) ALDC12 (b) ALDC6

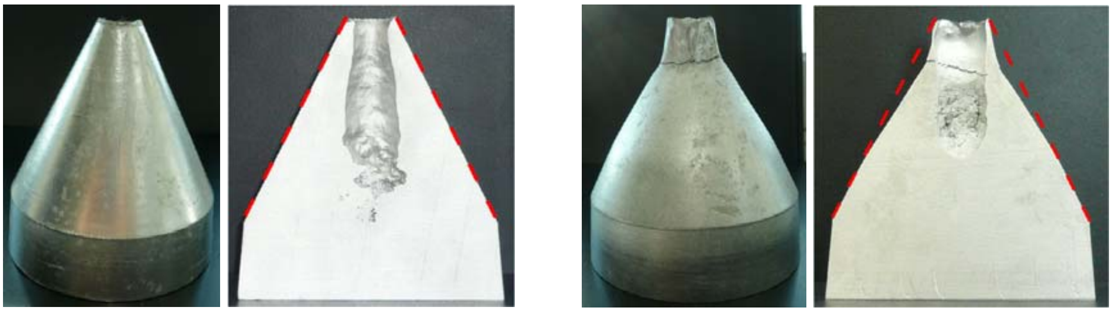


Fig. 6. Surface and Cross sections of the Tatur test castings.

In general, liquids contract on freezing because of the rearrangement of atoms from a rather open random close-packed arrangement to a regular crystalline array of significantly denser packing. The densest solids are those that have cubic close packed symmetry. Thus the greatest values for contraction on solidification are seen for these metals. Mg is known that the contraction is to be in 4.1% during solidification [12]. The exceptions to this general pattern are those materials that expand on freezing. These include silicon, cerium and bismuth [12]. The silicon have a contraction rate of -2.9% on solidification, therefore, ALDC12 didn’t show the hot tearing in comparison with ALDC6 because of ALDC12 have a silicon approximately 10%.

4. Summary

The results showed that Al-Mg alloy was had a higher residual stress and distortion generated after solidification than Al-Si alloy. Because of these residual stress and distortion, defects were evident in Al-Mg alloy at the predicted area by simulation while there was no visible defect observed in Al-Si alloy. Therefore, it was suggested that adequate die temperature and casting process optimization to control the above defects of Al-Mg alloy.

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