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Effect of Ultrasonic Treatment on the Microstructures and Mechanical Properties of Die Casting Aluminum Alloys

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Ultrasound has been successfully applied to the cleanness of various cast metals through elimination of gas species and non-metallic inclusions, as well as grain refinement. In the present study, effects of ultrasonic treatment on the microstructure and mechanical properties of die casting alloys were examined by radiating ultrasonic vibration(UV) to a molten aluminum alloys in order to broaden the applications and improve the structural properties of Al-Si based die casting aluminum alloys. In this experiment, an ultrasonic generator of 2kW power and piezoelectric transducer operated at 20kHz resonance frequency were used. The ultrasonic treated molten aluminum of about 1kg was poured into the preheated permanent mold coated with BN coating agent. Firstly, the fluidity was evaluated for comparing the castability improvement of UV treated aluminum alloys. Also, the apparent densities of treated alloys were measured with ultrasonic processing times. The microstructure changes of as-cast specimens were characterized with the optical microscopy(OM) and scanning electron microscopy(SEM). Tensile properties of UV treated aluminum alloys were compared with non-treated alloys and other general casting alloys. It was shown that the ultrasonic treatment could be broadening the applications of die casting aluminum alloys through the microstructure and mechanical property improvement.

Keywords: *Ultrasonic, die casting, aluminum, fluidity, tensile properties.*

1. Introduction

The main sources of gas porosities in aluminum castings is hydrogen, which is the only gas with significant solubility in molten aluminum[1]. During solidification of molten aluminum alloys, dissolved hydrogen in excess of the maximum solid solubility of hydrogen in the alloy precipitates out in molecular form and forms what is known as hydrogen porosity. There was little concern for hydrogen in the melt for the production of high pressure die castings. The rapid solidification tended to freeze the hydrogen in the castings. However, more intricate casting structures, and greater demand on the casting properties has meant that hydrogen content can no longer be ignored[2]. For this reason, hydrogen content in a die casting aluminum alloy must be kept as low as possible, especially for high integrity pressure tight or heat treated castings.

Several methods are usually used to reduce the hydrogen content in aluminum melts. These methods include rotary degassing using nitrogen or argon or mixture of these with chlorine as a purge gas[3], tablet degassing using hexachloroethane(C_2Cl_6)[3], vacuum degassing[4], and ultrasonic degassing[5]. Ultrasonic degassing, an environmentally clean and relative inexpensive technique, uses high intensity ultrasonic vibrations to generate oscillating pressures in molten aluminum. The alternating pressure above critical threshold point creates numerous cavities in the liquid metal. Hydrogen is removed by diffusing to the cavitation bubbles and escape from the melt. The majority of the traditional ultrasonic applications are focused on the degassing of AlSiMg alloys, such as A356 alloy[6].

But today, die casting is most popular process to make light weight casting parts for the automobile applications because of low manufacturing cost and high production rate. So, the ultrasonic degassing, as a new method for improving the molten metal cleanliness for producing high quality die castings, has attracted a great deal of attention.

This paper presents an experimental study in order to investigate the effects of different ultrasonic processing parameters on the degassing efficiency of die casting aluminum alloys compared with custom casting aluminum alloys using a PZT based ultrasonic equipment. The degassed molten aluminum alloys were evaluated in terms of density, fluidity and mechanical properties with changing vibration time and acoustic output power.

2. Experimental

2.1 Experimental material

Commercial Al-Si-Cu based die casting alloys were used as the raw materials. Their chemical compositions were listed in Table 1. Also, the Al-Si-Mg based A356 alloy was used to comparing with die casting alloys.

Table 1. Chemical compositions of raw materials

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn
ALDC10	9.27	0.81	2.47	0.13	0.23	0.00	0.08	0.00
ALDC12	10.7	0.86	1.87	0.16	0.18	0.00	0.05	0.72
A356	6.93	0.14	0.012	0.01	0.38	0.02	0.003	0.008

2.2 Experimental equipment

The ultrasonic treatment equipment used in this experiment consists of generator and transducer with the maximum output power of 2kW and resonance frequency of 20kHz. The In this process, ultrasonic vibration was injected into the aluminum melt by using a 40mm diameter of cylindrical radiator made of titanium alloy Ti-6Al-4V.

2.3 Experimental procedures

The aluminum alloy with the weight of 0.7kg was melted in a graphite crucible held at 750℃. And then, the graphite crucible containing aluminum melt was transferred into the other electric furnace. When the temperature of aluminum melt was 700℃, the cylindrical radiator was immersed into the melts about 10mm in depth. The ultrasonic generator was turned on. For each experiment, the ultrasonic power is 0.4kW, 0.8kW, 1.2kW and 1.6kW, respectively. The ultrasonic treatment time is 15sec, 30sec, 45sec and 60sec, respectively. After ultrasonic treatment, the aluminum melt of 640℃ was poured into spiral fluidity test and mechanical test mold preheated at 200℃. The reduced pressure test(RPT) was used to determine the porosity levels of the ultrasonic treated melts. Molten alloy was solidified under a reduced pressure of 120mmHg. The densities of the RPT specimens were measured using the apparent density measurement method[5]. The tensile test specimens were prepared according to the ASTM E8 specifications with 6.35mm in diameter. For comparing, the specimens without ultrasonic treatment were also prepared. The microstructures of fractured specimen were observed with optical microscopy and scanning electron microscopy.

3. Results and discussion

Fig. 1 shows the effect of ultrasonic treatment on the feed length of ALDC10 alloy melt for different ultrasonic treatment times at 700℃ melt temperature and using 1200W output power. The feed length was increased with ultrasonic processing times. The feeding distance of ultrasonic treated aluminum melts for 30sec was increased by two times than that of the non-treated aluminum melt. When the high intensity ultrasonic vibration is applied into melt, the cavitation creates tiny bubbles. These cavitation bubbles will float to the melt surface accompanying with non-metallic inclusions adsorbed onto the bubble surface. Then, the melt is cleaned and more easily fills into the mold cavity. Fig. 2 shows the cross-section image of the fluid test specimens as a function of processing time. As the ultrasonic treatment decreased the hydrogen content, the porosity of front end of molten metal was decreased. It can be considered that the ultrasonic action is effective on the improvement of die casting aluminum alloy castability by removing inclusions and hydrogen gas.

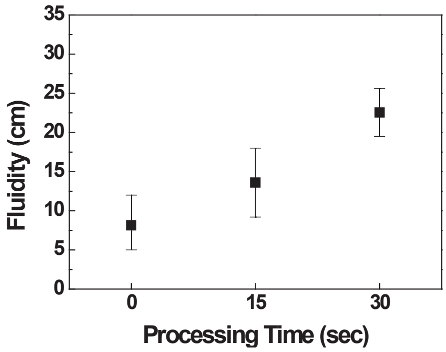

Fig. 1 Flow length of the ALDC10 alloy as a function of processing time.

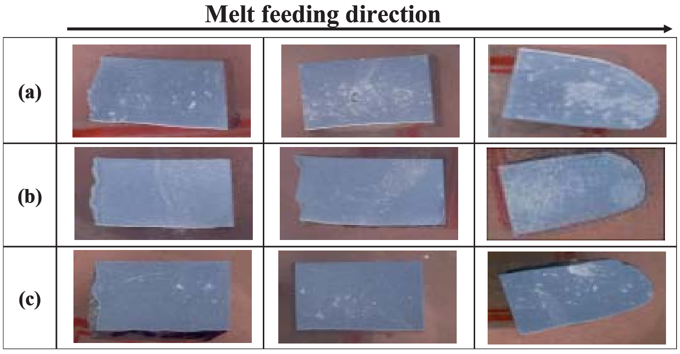

Fig. 2 Cross-section image of fluid test ALDC10 alloy as a function of processing time : (a) 0sec, (b) 15sec and (c) 30sec.

Fig. 3 shows the apparent density changes of the RPT test ALDC10 alloy as a function of ultrasonic treatment times. The maximum alloy density of 2.67kgdm^{-3} was obtained after 60sec ultrasonic treatment at 700℃ melt temperature and using 1200W output power. Fig. 4 illustrates the cross-section images of RPT test specimens with ultrasonic processing times. The porosity was remarkably decreased with increasing processing times. The top of the RPT test ingot was changed from convex to concave surface due to the elimination of hydrogen gas from the melt.

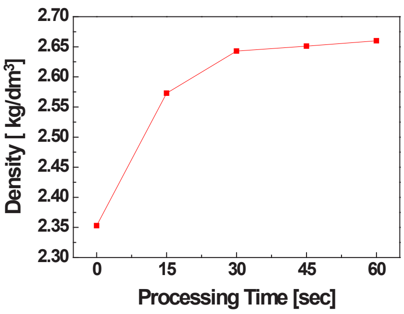

Fig.3 Density of the ALDC10 alloy as a function of processing time.

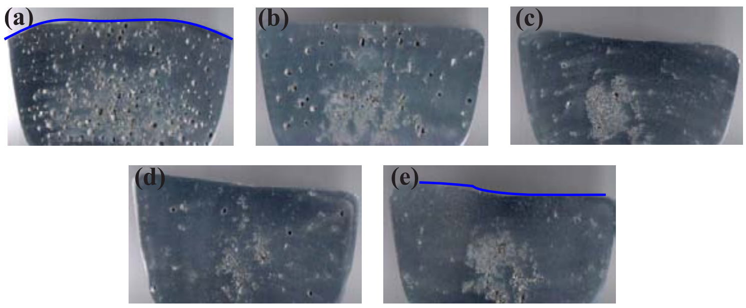

Fig.4 Cross-section image of RPT test ALDC10 alloy as a function of processing time : (a) 0sec, (b)15sec, (c) 30sec, (d)45sec and (e)60sec.

Fig. 5 shows the tensile strength change of the ALDC10 die casting alloy as a function of ultrasound electric output power and processing time. The tensile strength was increased in early time at all electric powers, but the strength was decreased again with increasing the ultrasonic time. Elongation also showed the same tendency to the tensile strength variations. It was reported that the mechanical properties of aluminum casting alloy was strongly dependent on the degassing efficiency of hydrogen gas by ultrasonic cavitation[7]. So, the degassing efficiency is related with various processing parameters, such as, processing time, ultrasonic power, melt temperature and volume of a melt. In this study, it was estimated that the alternating trend of tensile properties was caused by the low temperature of melt and high injection power of ultrasound. The high ultrasound power will increase the degassing efficiency by creating many cavitation bubbles, but the bubbles will not float directly to the melt surface, and trapped in the melt, when the melt is in the low temperature. Fig. 6 shows the temperature variations of aluminum melts after ultrasonic treatment for each processing times. The melt temperatures were cooled down just above the pouring temperature of 640℃ during ultrasonic treatment.

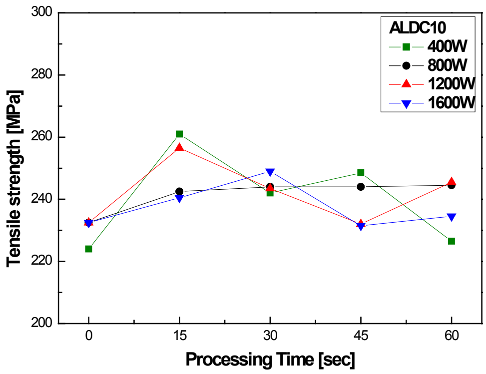

Fig.5 Tensile strength of the ALDC10 alloy as a function of output power and processing time.

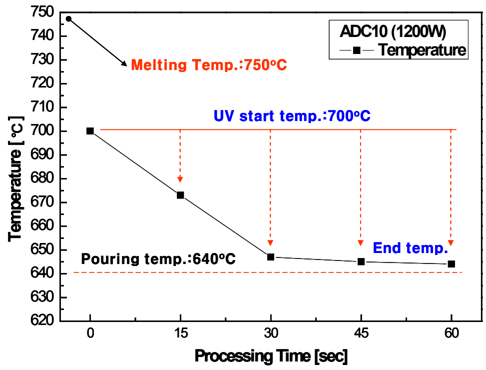

Fig.6 Temperature variations of aluminum melts after ultrasonic treatment as a function of processing time.

So, the tendency of tensile strength could be explained by the cavitation bubbles entrapment within the aluminum melt. It can be observed in the microstructures as shown in Fig.7. Fig. 7 shows the optical microstructure of tensile specimens treated at 1200W ultrasound power. The bubble pores were repetitively observed in the different processing times. The mechanical properties of die casting alloy will be improved by removing this tiny bubbles in the melts via increasing the melt temperature and processing time. Fig. 8 shows the tensile strength of A356 alloy as a function of processing time for comparing with the aluminum die casting alloys. In the case of A356 alloy, the tensile strength was smoothly increased with processing times. It was assumed that the degassing efficiency was also dependent on the physical properties of each casting alloy, such as, viscosity, surface tension and solidification characteristic.

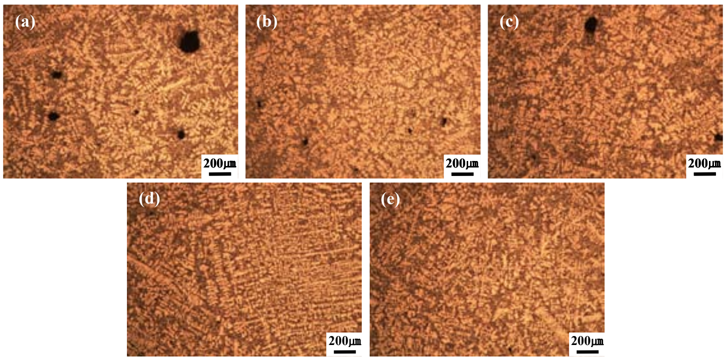

Fig.7 Microstructure of tensile test ALDC10 alloy as a function of processing time : (a) 0sec, (b)15sec, (c) 30sec, (d)45sec and (e)60sec

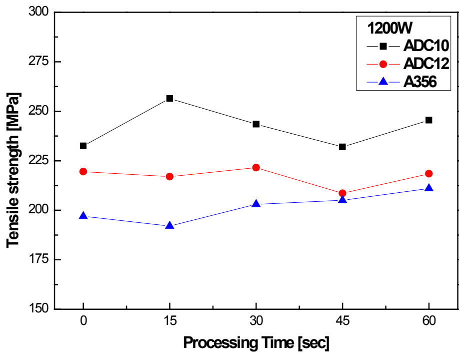

Fig.8 Tensile strength of A356 alloy as a function of processing time for comparing.

4. Conclusions

The effects of high-intensity ultrasonic treatment on the castability and mechanical properties of die casting alloys are investigated. The results indicate that the fluidity of molten ALDC10 alloy is increased with increasing ultrasonic processing time. It could be the effect of the float of cavitation bubbles which accompany with tiny inclusions adsorbed on the bubble surface. The maximum alloy density of 2.67kgdm^{-3} was obtained after 60sec ultrasonic treatment at 700℃ melt temperature and using 1200W output power. The tensile strength was increased in early time at all electric powers, but the strength was decreased again with increasing the ultrasonic time. The alternating tendency of tensile strength could be explained by the cavitation bubbles entrapment within the low temperature aluminum melt. So, the mechanical properties of this alloy could be improved by removing this tiny bubbles in the melts via increasing the melt temperature and processing time. This study shows that the ultrasonic treatment could be broadening the applications of die casting aluminum alloys through the microstructure and mechanical property improvement.

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