Ultrasonic Degassing of Molten Aluminum under Reduced Pressure

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Keywords: ultrasonic vibration, degassing, vacuum, aluminum alloy

Abstract

Ultrasonic degassing, an environmentally clean and cheap technique, is an efficient way of degassing in a static volume melt. Vacuum degassing has also been tested a beneficial and clean method in producing high quality products. Combination of these two techniques will make degassing more efficient. An experimental device which combines the vacuum degassing and ultrasonic degassing has been built in Oak Ridge National Laboratory recently. Parametric studies have been carried out to investigate the efficacy of the ultrasonic degassing of molten Aluminum alloy under reduced pressure. This article reports the initial experimental results on ultrasonic degassing under reduced pressure.

Introduction

Porosity is one of the major defects in aluminum alloy castings. The presence of porosity can be detrimental to the mechanical properties and corrosion resistance of the castings. Porosity in castings occurs because of the precipitation of gas from solution during solidification or the inability of the liquid metal to feed through the interdendritic regions to compensate for the volume shrinkage associated with the solidification. Hydrogen is the only gas that is appreciably soluble in molten aluminum [1-2]. Thus the control of the dissolved hydrogen levels in the molten aluminum alloy is critical for the production of high-quality castings. The most effective way of reducing hydrogen porosity is degassing [3-5]. Several methods are currently in use to degas aluminum. These methods include the use of nitrogen or argon or mixture of either of these with chlorine as a purge gas. There are also other techniques such as tablet degassing by using hexachloroethane (C_2Cl_6) tablets, vacuum degassing, and ultrasonic degassing.

Ultrasonic degassing, an environmentally clean and cheap technique, uses high intensity ultrasonic vibrations to generate oscillating pressures in molten aluminum. The alternating pressure creates a large number of small cavities in the liquid. Some of these cavities grow rapidly under the influence of the alternating pressure and the unidirectional diffusion of dissolved hydrogen from the melt to the cavities. These large bubbles coagulate and float to the surface of the melt due to gravity and the acoustically induced flows in the melt [6-8].

Research on ultrasonic degassing was initiated in the former Soviet Union [9, 10]. Few attempts have been made to study ultrasonic degassing in North America. Recently an experimental device has been built in Oak Ridge National Laboratory for the degassing of aluminum using ultrasonic vibration at a frequency of 20 kHz and vibration intensities up to 1500 W. Ultrasonic degassing has been tested in different volumes of aluminum melt at various initial hydrogen concentrations, processing temperatures and durations.

Vacuum degassing, a practical technique used in Europe, has been demonstrated as a beneficial and clean method in producing high quality products [3, 11]. By creating a vacuum above the melt surface, the hydrogen level in the melt will decrease. Even partial vacuum have been found to be effective. This technique was shown to be an effective way of removing dissolved gases, oxides and other impurities. The mechanical strength of vacuum-degassed castings is greater than that of chlorine-degassed ones [3].

Combination of vacuum degassing and ultrasonic vibration may lead to much faster degassing in aluminum melt. An experimental device which combines the vacuum degassing and ultrasonic degassing has been built. Parametric studies have been carried out to investigate the efficacy of the ultrasonic degassing of molten Aluminum alloy under reduced pressure. This article reports the experimental results and discusses the efficiencies of degassing using various methods.

Experimental Method

A356 alloy was used in this investigation. Its chemical composition is shown in Table I.

Table I Chemical Composition of A356 alloy

Element	Al	Cu	Fe	Mg	Mn	Si	Ti	Zn
Wt.%	92.5	0.1	0.1	0.35	0.05	7.2	0.1	0.05

Figure 1 shows the experimental setup which can perform vacuum degassing with the assistance of ultrasonic vibration. It consisted mainly of an ultrasonic generator, a transducer, a horn and radiator to transmit ultrasonic vibration into aluminum melt, a furnace, and a vacuum chamber. The transducer was capable of converting up to 1.5 kW of electric energy at a resonant frequency of 20 kHz. The crucible inside the electric furnace could hold molten aluminum alloys up to 800g. The minimum remnant pressure of this vacuum chamber was 50mTorr.

J. F. Grandfield and D. G. Eskin (Eds.), *Essential Readings in Light Metals*

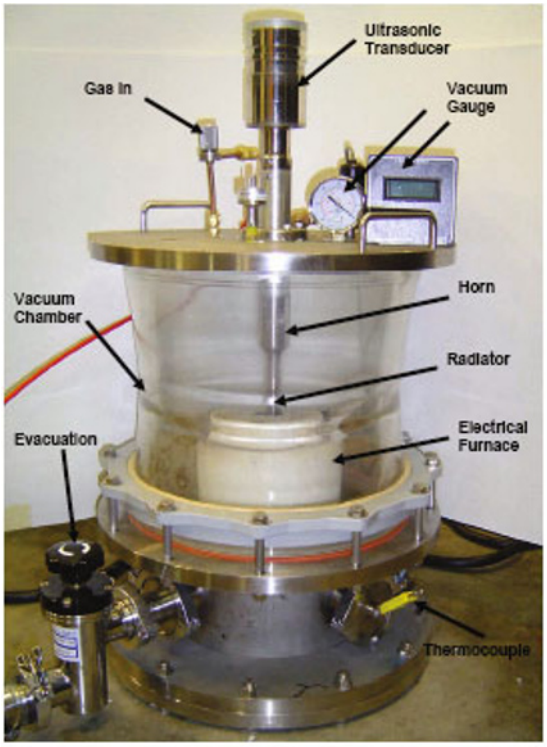

Figure 1: Schematic view of the chamber which can perform vacuum degassing with the assistance of ultrasonic vibration.

Ultrasonic degassing was carried out in aluminum A356 melt under three conditions. These conditions included the humidity, the temperature of the melt, and the volume/size of the melt or the size of crucible. The humidity was varied from 40% to 60%. Four melt temperatures, 620°C, 660°C, 700°C and 740°C, were tested. The weight of the melt was 0.2 kg, 0.6 kg and 2 kg, respectively.

The process parameters studied under vacuum degassing were the remnant pressure and degassing time. The remnant pressure was varied from 760 Torr to 0.1 Torr. The degassing time was from 1 to 30 minutes. Vacuum degassing with assistance of ultrasonic vibration was investigated under two different remnant pressures: 100 Torr and 1 Torr, respectively.

Reduced pressure test (RPT) was employed to determine the porosity level of the cast. Molten alloy (~120 g) was poured into a preheated thin-walled iron cup and allowed to solidify under a reduced pressure of 50 mm of Hg (i.e., a vacuum of 28inches Hg). Pressures of 50 to 100 mm of Hg were usually used for RPT [12, 13]. The RPT specimens were sectioned in the middle vertically and were polished to reveal the extent of the hydrogen porosity. Densities of RPT specimens were measured by using the apparent density measurement method [4]. The specimen was weighed in air and in water. The density, *D*, of the specimen is given in the following equation:

$$D = \frac{W_a}{W_a - W_w}$$

where, W_a and W_w are the weights of the specimen measured in air and water, respectively.

Experimental Results and Discussion

Degassing by ultrasonic vibration

Ultrasonic degassing was tested in different volumes of aluminum melt at various initial hydrogen concentrations, processing temperatures and durations.

Figure 2 shows the ultrasonic degassing rates in molten A356 alloy prepared at 740°C under different humidity levels or initial hydrogen concentrations. The experiments were carried out using a crucible containing 0.2 kg of aluminum melt. Without ultrasonic vibration, the density of the specimen cast under humidity 60% was much lower than that cast under humidity 40%. With ultrasonic vibrations, the density of the specimen increased rapidly with increasing ultrasonic processing time in the first minute and then reached a plateau density, which corresponds to the steady-state hydrogen concentration in the melt at 740°C. This trend was true for specimens cast under both humidity levels. The results shown in Figure 2 suggest that degassing in a small aluminum melt was extremely quick. No matter what the initial hydrogen concentrations are, degassing could be achieved within one minute. The humidity had little effect on the time required for degassing using ultrasonic vibrations.

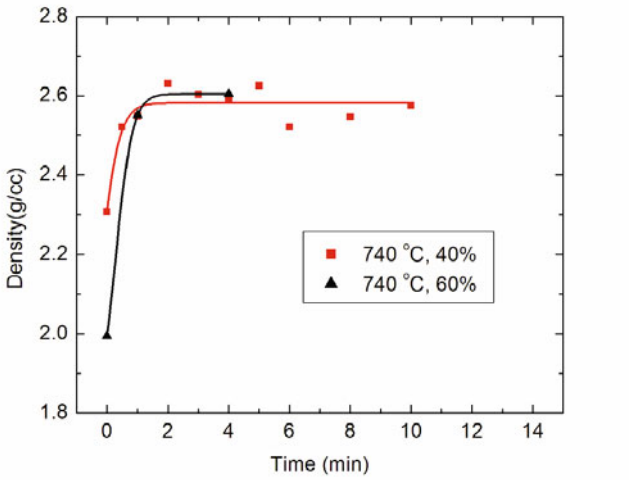

Figure 2: The measured density of the RPT specimen as a function of ultrasonic processing time in the melt of different initial hydrogen concentrations.

Figure 3 shows the efficiency of ultrasonic degassing in A356 alloy melts under various melt temperatures. The results were obtained in a crucible containing 0.2 kg aluminum alloy. It took one minute of ultrasonic vibration for the melt to reach a steady-state density plateau when the melt was ultrasonically processed at a temperature of 700°C or 740°C. The processing time required to degas the melt (to reach the steady-state density plateau) increased with decreasing melt temperature. It took almost 10 minutes to degas the melt held at 620°C, much longer than in the melt held at temperatures higher than 700°C. This

indicates that the degassing efficiency decreases with decreasing processing temperature. Figure 3 also indicates that the plateau density is not sensitive to the processing temperature in the range between 620°C and 740°C. It takes longer processing time to reach the plateau density when the processing temperature is low but as long as the plateau density is reached, the porosity levels in the RPT specimens are identical.

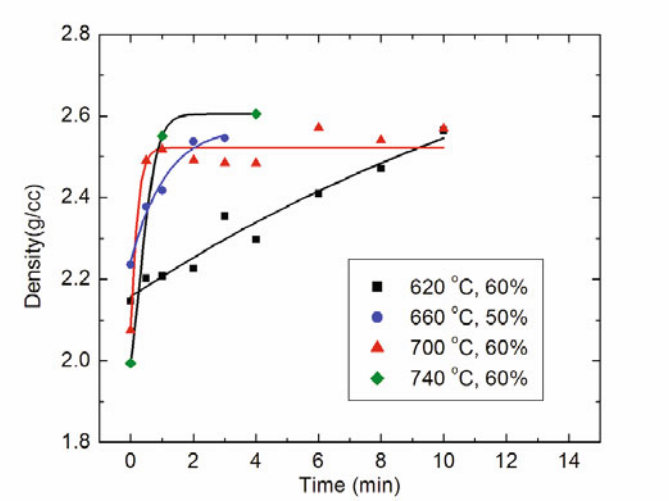

Figure 3: The measured density of the RPT specimen as a function of ultrasonic processing time in melt at different processing temperatures.

The effect of the melt volume on the efficiency of ultrasonic degassing is investigated. The experiments were carried out in melt at 700°C under humidity 60%. The weights of the melts were 0.2 kg, 0.6 kg, and 2.0 kg respectively. As illustrated in Figure 4, the ultrasonic processing time required to reach the steady-state plateau density increases with increasing volume/weight of the melt. It took 1 min to degas the 0.2 kg melt, 4 min to degas the 0.6 kg melt, and almost 7 min to degas the 2.0 kg melt. Degassing rate in a large volume melt was much slower than that in a small melt.

Vacuum degassing

Hydrogen level in the melt can be decreased by creating a vacuum above the melt surface. Even partial vacuum have been found to be effective in reducing the hydrogen level in the melt. Figure 5 shows the measured densities of the RPT specimen using melt prepared under the remnant pressure of 0.1 Torr, 1 Torr, 10 Torr, 100 Torr and 760 Torr respectively for 30 minutes. It is evident that the degassing rates are slow using vacuum degassing. It takes about 20 to 30 minutes to get the steady-state plateau density for a 0.6 kg melt. As shown in Figure 5, the density of the RPT specimen decreases with the decrease of the remnant pressure. The hydrogen content in the melt decreases with the decrease of the remnant pressure.

Figure 6 shows the measured densities of the RPT specimen as a function of treatment time under different remnant pressure..

Most of the experiments were carried out in melts at 720°C under humidity of 50% except one which was degassed under humidity of 60% when remnant pressure was 100 Torr. The weight of the melt was 0.6 Kg.

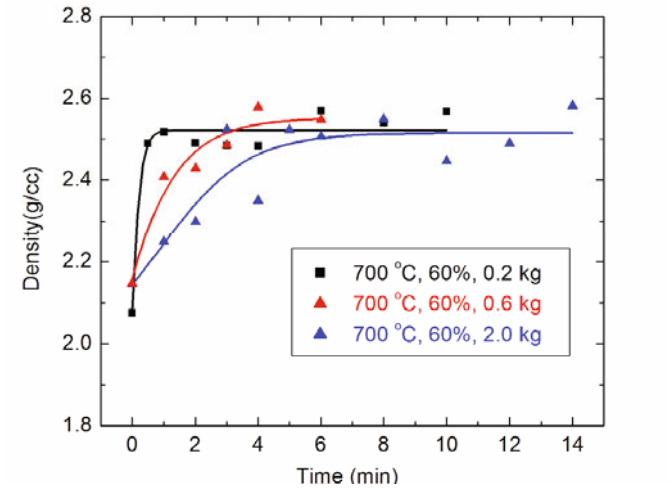

Figure 4: The measured density of the RPT specimen as a function of ultrasonic processing time in melt of different sizes.

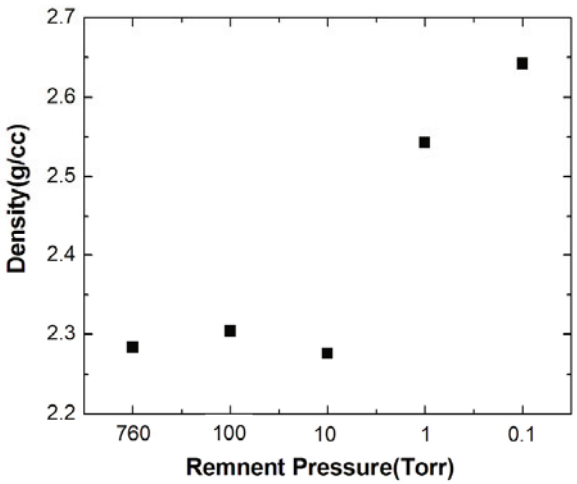

Figure 5: The measured densities of the RPT specimen as a function of remnant pressure. The melts were held at reduced pressure for 30 minutes before RPT.

Ultrasonic Degassing under reduced pressure

Ultrasonic degassing under reduced pressure was investigated in melt of 0.6 kg. Data marked with triangles in Figures 7 and 8 show the efficiency of ultrasonic degassing under two remnant pressure levels, 100 Torr and 1 Torr, respectively. It was much faster to reach the plateau density using the combination of ultrasonic degassing and vacuum degassing than the other

degassing methods. For comparison reasons, data obtained using ultrasonic vibration under normal pressure, marked using filled squares, and data obtained using vacuum degassing, marked using filled circles, are also plotted in Figures 7 and 8. As illustrated in both figures, the most efficient way of degassing is ultrasonic degassing under reduced pressure and slowest method for decreasing is vacuum degassing. It took just 1 minute for ultrasonic degassing under reduced pressure to reach the steady-state density, 4 minutes for ultrasonic degassing alone, and more than 20 minutes for vacuum degassing.

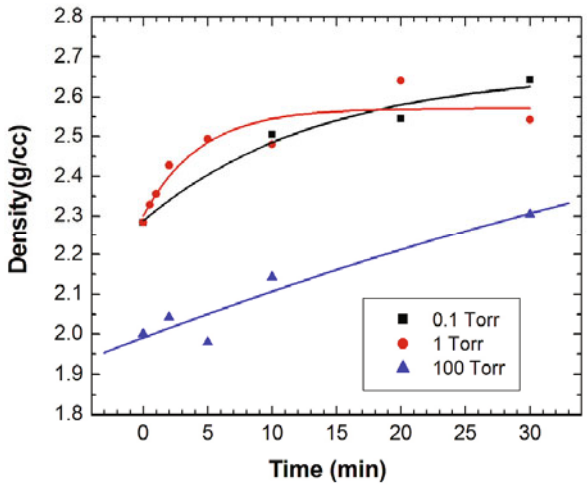

Fig. 6: The measured densities of the RPT specimen as a function of treatment time under different remnant pressure.

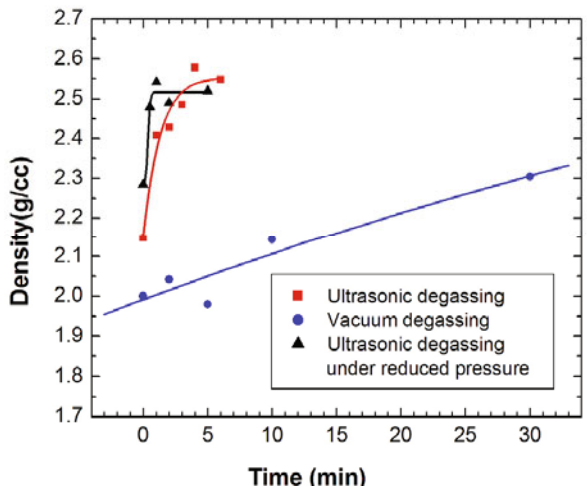

Fig. 7: The efficiency of different degassing techniques when remnant pressure is 100 Torr. The techniques include ultrasonic degassing, vacuum degassing and ultrasonic degassing under reduced pressure.

Using reduced pressure improves the efficiency of ultrasonic degassing. Even under a partial vacuum condition such as 100 Torr, the efficiency of ultrasonic degassing is increased. However, the value of remnant pressure could affect the value of the steady-state plateau density during ultrasonic degassing. As indicated in Figures 7 and 8, the steady-state plateau density during ultrasonic degassing under reduced pressure 100 Torr is lower than that under 1 Torr. It results in the fact that remnant pressure will influence the dynamic equilibrium of the liquid-gas system. The lower the remnant pressure, the lower the hydrogen content in the melt.

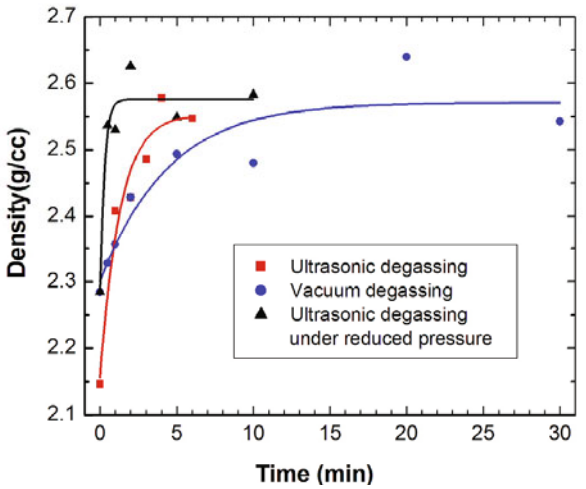

Fig. 8: The efficiency of different degassing techniques when remnant pressure is 1 Torr. The techniques include ultrasonic degassing, vacuum degassing and ultrasonic degassing under reduced pressure.

Conclusion

1. Ultrasonic degassing at is an efficient way of degassing in the small volume melt. The degassing rate in the temperature range between 700°C and 740°C is faster than that in the temperature range between 620°C and 660°C. The ultrasonic degassing rate in a large volume melt is obviously lower than that in a small volume melt.

2. The humidity/initial hydrogen concentration has little effect on the degassing efficiency using ultrasonic vibrations.

3. The hydrogen content in the melt decreases with the decrease of the remnant pressure under vacuum degassing. But the efficiency of vacuum degassing is very low.

4. Compared with vacuum degassing and ultrasonic degassing, the most efficient way of degassing is ultrasonic degassing under reduced pressure.

Acknowledgment

This research was supported by the United States Department of Energy, Assistant Secretary for Energy Efficiency and Renewable Energy, Industrial Technologies Program, Industrial Materials for the Future (IMF) Program, Aluminum Industry of the Future, under contract No. DE-PS07-02ID14270 with UT-Battelle, LLC. The authors would like to thank Ohio Valley

Aluminum Co. and Secat Inc for providing industrial support, E.C. Hatfield for set up of the ultrasonic degassing unit, and Sonic Inc. for providing radiators that work at high temperatures.

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