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Effects of Vibration Frequency on Ultrasonic Degassing of Molten Aluminum Alloy

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Abstract: The effect and mechanism of ultrasonic vibration of diverse frequencies on the degassing of 7050 and 1060 aluminum alloy melt at different temperature ranges were studied through the detection of hydrogen content by HYSCAN-II apparatus. The results show that the hydrogen content of the melt treated by ultrasound is evidently reduced; the hydrogen content of the melt increases as the temperature increases; while the temperature of metal liquid heightened from 660 to 720°C, this effect is slow down, but the degassing efficiency changed little; both the efficiency and effect treated by ultrasonic vibration of 15 kHz frequency are better than that of 20 kHz frequency. The cavitation effect caused by ultrasonic vibration creates plenty of cavitation bubbles. These bubbles can absorb and carry away the hydrogen in metal liquid when they grow up and collapse. Vibration frequency plays a decisive part in cavitation bubble growth and the diffuseness of hydrogen in metal liquid.

Key words: Degassing, hydrogen diffusion, ultrasonic, cavitation bubble, frequency

INTRODUCTION

Hydrogen is the main gas in aluminum alloy, accounts for about 85% (Puga *et al*., 2009; Gruzleski and Closset, 1990), so the gas content of aluminum liquid can be approximately equal the hydrogen content. In fact, removing the hydrogen is vital for degassing. As a kind of clean pollution-free way for removing gas, ultrasonic degassing gets more and more attention in recent years (Jian *et al*., 2005; Khalifa *et al*., 2008; Feng *et al*., 2008). Puga *et al*. (2009) has studied the processing parameters what affect degassing efficiency of AlSi9Cu3 melt such as ultrasonic power, frequency, melt temperature, processing time. He found that the ultrasonic frequency changing between 18.5 and 19.8 kHz has little effect on the degassing efficiency, but other parameters such as ultrasonic power, liquid temperature and processing time influence the degassing efficiency obviously. A research group (Puga *et al*., 2011; 2013) in Portugal has used self adaptable units for ultrasonic degassing during the last five years. Li *et al*. (2007) has studied the influence of the melt's processing methods on ultrasonic degassing of Al-1.65% Si alloy when vibration frequency changes between 26.5 and 27.5 kHz and his research results show that increasing the frequency of ultrasonic will improve the degassing effect.

The above studies of ultrasonic dega-ssing were based on a higher frequency and a relative narrow frequency range. This article mainly focuses on the effects of vibration frequencies from 15 to 20 kHz on ultrasonic degassing of 7050 and 1060 aluminum alloy melt. In theory, vibration with a frequency 15 kHz does not belong to ultrasonic, but in fact, it is usually regarded as ultrasonic for its similar effects in the practical application.

EXPERIMENT

Materials and equipment: The materials used in the experiments are 7050 aluminum alloy and industry pure aluminum 1060 (Al mass fraction 99.6%). The volumes of the melting charge are both 10 kg.

The experimental schematic diagram was shown in Fig. 1, the main apparatuses are a set of homemade ultrasonic generator with the output power from 0 to 2000 W and frequency from 14 to 22 kHz, which can adjust its output power and frequency to the different loads; Two sets of ultrasonic vibration system which is comprised of a PZT ceramic transducer, a No. 45 horn and a Φ50×110 mm titanium alloy radiator and of which the natural frequency are 15 and 20 kHz, respectively; a set of HYSCAN-II hydrogen measurement device made by Severn Science Corporation in U.K.. The principle of this detection gauge is based on decompression technology. Specifically, the vacuum pump decreases press swiftly after 100 g metal liquid being poured into sample chamber.

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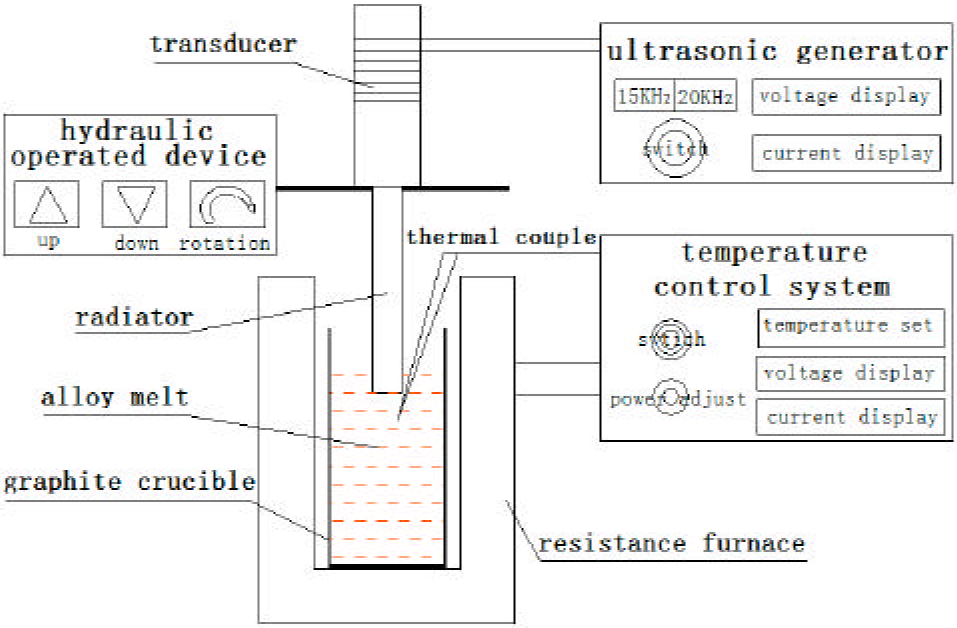

Fig. 1: Experimental schematic diagram of ultrasonic degassing of metal liquid

Table 1: Experimental parameters

Experimental parameters	Parameter value
Ultrasonic power P (W)	1000
Ultrasonic frequency f (kHz)	15, 20
Melt temperature of introducing ultrasonic T (°C)	660, 680, 700, 720
Ultrasonic processing time t (sec)	0, 60, 12, 180, 240, 300

Then, the specimen starts to curdle while sample chamber and vacuum system are separated from vacuum pump. After that, hydrogen gas is set off during metal solidification and detected by a Pirani manometer. In addition, there are some auxiliary instruments such as a resistance furnace, a graphite crucible with an inner diameter 180, 18 mm thick and 200 mm high, a timer and several thermocouples.

Experimental procedure: Firstly, the graphite crucible filled with the materials were placed in the resistance furnace and heated to 800°C. When the materials were completely melted, the molten melt should be fully stirred and the oxidation layer removed. Then the crucible was taken out from the furnace and cooled in the air. When the metal liquid temperature dropped to the desired conditions (Table 1) for tests, the preheated ultrasonic radiator was inserted vertically 30 mm deep into the liquid. Next, the ultrasonic generator power supply was started up and ultrasonic vibrations of different parameters (Table 1) were introduced into the aluminum. In each test, 100 g melt treated with ultrasonic vibration was fetched by a heated scoop and poured into the sample chamber of HYSCAN-II device and hydrogen content can be read in the display screen. The error of hydrogen content measurement was 0.01 cm^3 100 g^{-1}.

According to Table 1, ultrasonic of 20 and 15 kHz would be respectively applied to the melt at each temperature and the hydrogen content was detected every 60 sec.

RESULTS AND ANALYSIS

The pore distribution of ingot section was shown in Fig. 2, which the ingot was treated with ultrasonic vibration of 20 and 15 kHz at 680°C. From the Figure, it was seen that the pores obviously reduced under ultrasonic vibration, especially under the 15 kHz vibration. Hydrogen content of the samples without ultrasonic treatment and with ultrasonic treatment of 20 and 15 kHz were 0.64, 0.34 and 0.19 cm^3 100 g^{-1}. Thus, ultrasonic vibration of 15 kHz frequency was more beneficial to degassing. Besides, it could be clearly seen from Fig. 2(a) that the pores were small at the bottom but their size increase as they moved from bottom to top. This was mainly decided by the degassing process which can be divided into three phases: Bubble formation, growth and overflow (Eskin, 1998; Xu *et al*., 2004).

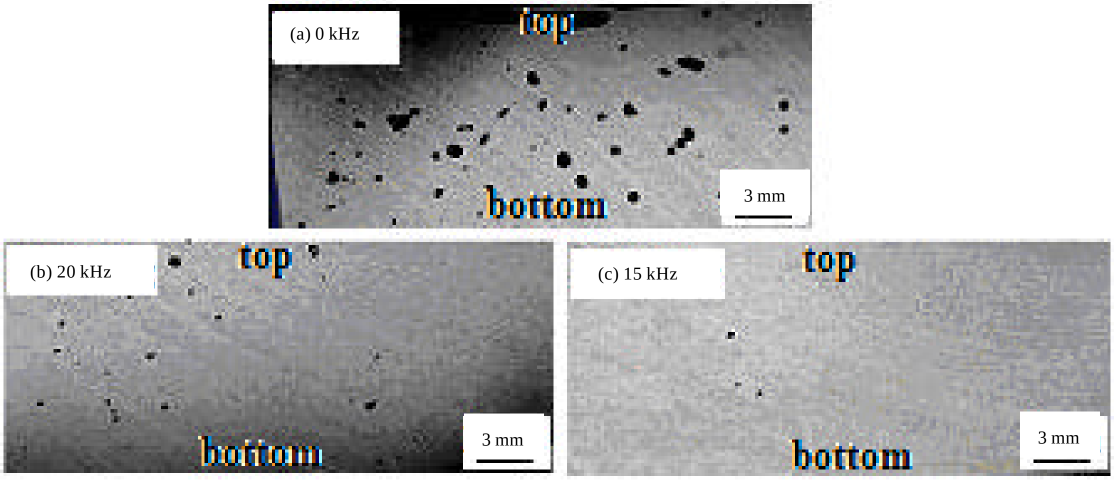

Fig. 2(a-c): Pore distribution in ingot section of 7050 aluminum alloy, (a) 0 kHz, (b) 20 kHz and (c) 15 kHz

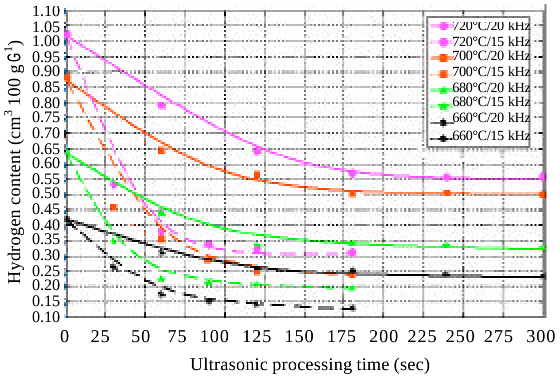

Fig. 3: Relation curves of hydrogen content of 7050 aluminum alloy melt and ultrasonic processing time

Effects of vibration frequency on ultrasonic degassing of 7050 aluminum alloy: Degassing efficiency η_{deg} can be defined as follows:

$$\eta_{deg} = \frac{C^0_{H_2} - C^t_{H_2}}{C^0_{H_2}} \times 100\% \qquad (1)$$

where, C^0H_2 is the hydrogen content of the melt without ultrasonic treatment; C^tH_2 is the hydrogen content of the melt with ultrasonic treatment.

Figure 3 showed the curves of hydro-gen content versus ultrasonic processing time at different temperatures and vibration frequency. It was seen that hydrogen content in the alloy melt increased as temperature increased at a certain temperature range, but generally speaking, the melt temperature influenced little on ultrasonic degassing. Both degassing efficiency and degassing effect of the melt treated with ultrasonic vibration of 15 kHz were higher than that of 20 kHz.

Table 2: Degassing efficiency of two kinds of vibration frequency

Temp. (°C)	η_{deg} (20 kHz, 300 sec) (%)	η_{deg} (15 kHz, 180 sec) (%)
660	45	69
680	50	70
700	44	73
720	46	70

As shown in Fig. 3, hydrogen content of the aluminum alloy melt without ultrasonic treatment (namely ultrasonic processing time was 0 sec) was respectively 0.42 cm^3 100 g^{-1} at 660°, 0.64 cm^3 100 g^{-1} at 680°C, 0.89 cm^3 100 g^{-1} at 700°C and more than 1.03 cm^3 100 g^{-1} at 720°C. It indicated that the hydrogen content of the melt increased with the temperature of the melt.

Hydrogen content decreased when ultrasonic vibration was introduced into the metal liquid. Also, Degassing efficiency η_{deg} can be worked out by Eq. 1 as shown in Table 2. From Table 2, it was found that degassing efficiency was relatively high when metal liquid was treated with ultrasonic vibration of a lower frequency 15 kHz.

The above results were obtained when the values of ultrasonic pressure were the same. Eskin (1995) found that cavitation generated when ultrasonic pressure was higher than cavitation threshold. Cavitation bubble grew up under the alternating sound pressure. The wall of bubble became thinner and the partial pressure of hydrogen inside the bubble reduced in the expansion phase. At this time, hydrogen moved into bubbles from the aluminum liquid. While the partial pressure of hydrogen increased in the compression phase, hydrogen inside the bubble could not diffuse to the melt again for the thickening of bubble wall. Cavitation bubbles absorbed hydrogen from metal liquid continually during bubbles growing and then these bubbles floated out the liquid surface. At last, hydrogen of the melt decreased.

Vibration frequency would affect the critical radius of the cavitation bubbles (Thompson and Doraiswamy, 2000). To the ultrasonic vibrations with the same power, the critical radius of the cavitation bubbles increased with frequency. As a result, cavitation threshold increased and it was difficult for the formation of cavitation. Besides, with the increasing of frequency, the time of the expansion process of ultrasound shortened, so that the amplitudes of the cavitation bubbles decreased and the bubbles didn’t have enough time to grow up before encountering the next compressing phase. And then, the diffusion of hydrogen into the cavitation bubbles became more difficult. So, choosing the lower frequency of ultrasonic treatment could bring a better degassing effect and a higher degassing efficiency.

From Table 2, it was easily found that the temperature of the melt played little effect on the degassing efficiency. This result did not contradict the conclusions the literatures (Li *et al*., 2008) mentioned. They reached the conclusions under the conditions of lower ultrasonic power (acoustic intensity $I = 5W\ cm^{-3}$). It was true that the cavitation bubble fluctuated and grew up more difficultly with a lower ultrasonic power because melt viscosity increased as its temperature decreased. While with the high ultrasonic power ($I = 20W\ cm^{-3}$), acoustic energy could overcome the resistance for the increase of melt viscosity to some extent. This would weaken the effect of melt temperature on degassing efficiency.

Effects of the vibration frequency on ultrasonic degassing of 1060 aluminum alloy: Figure 4 showed the relationship between hydrogen content of pure aluminum melt and ultrasonic processing time under different treating conditions. It was known that when vibration frequency was 20 kHz, the hydrogen content decreased only a little and there was almost no degassing effect with ultrasonic treatment especially below 700°C. However, the ultrasonic degassing effect was still considerable when melt was treated with the vibration of 15kHz. From Fig. 4, under the same condition, the curves of hydrogen content under ultrasonic vibration of 20 kHz were always above the curves of 15 kHz. It was indicated that ultrasonic degassing efficiency of 15 kHz was better than that of 20 kHz.

The above results of ultrasonic degassing on 7050 and 1060 aluminum alloy were relative to the pulse spread of cavitation bubbles in metal liquid (Sun *et al*., 2009; Hsieh and Plesset, 1961). Pulse spread refers to the growth of the cavitation bubbles generated by the uneven mass transfer on the bubbles’ surface during the inflation and compression of the bubbles. Vibration frequency played an important role in the formation and growth of cavitation bubble. Ultrasonic vibration with a low frequency could improve the efficiency of cavitation so that it could promote the growth of bubble and the diffusion of hydrogen.

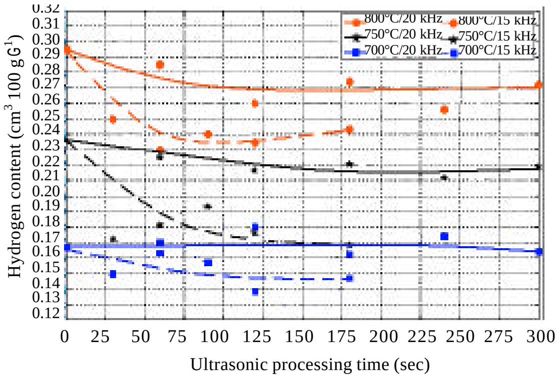

Fig. 4: Relation curves of hydrogen content of 1060 aluminum alloy melt and ultrasonic processing time

CONCLUSION

The temperature of the melt had less effect on degassing efficiency when the melt was treated by high power ultrasonic. However, in some certain temperature range, for 680 to 720°C, ultrasonic degassing effect became better as the temperature increased.

The degassing effect mainly depended on vibration frequency. Both the efficiency and effect of ultrasonic degassing in aluminum melt treated with a 15 kHz frequency vibration were better than that treated with a 20 kHz frequency vibration. The increment of the degassing efficiency η_{deg} was over 20% at least.

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