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Change of Aluminum Alloys Structure by Sono-Solidification

S. Gnapowski^{a*}, Y. Tsunekawa^b, M. Okumiya^b, K. Lenik^c

^a Kumamoto University, Graduate School of Science and Technology, Frontier Technology for Electrical Energy, Kumamoto University, 2-39-1 Kurokami, Kumamoto, 860-8555, Japan.

^b Toyota Technological Institute, 2-12-1 Hisakata, Tempaku-ku, Nagoya 468-8511, Japan

^c Fundamentals of Technology Faculty, Lublin University of Technology, ul. Nadbystrzycka 38, 20-618 Lublin, Poland

* Corresponding author. E-mail address: sgnapowski@wp.pl

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Abstract

This experiment utilized five Aluminum alloys with silicon content percentages of 7, 10, 12.6, 14.5 and 17(wt)%. Ultrasonic vibration was applied to improve the quality of aluminum alloys. Sono-solidification, in which ultrasound vibrations are applied to molten metal during its solidification, is expected to cause improved mechanical properties due to grain refinement. Observed by microstructure photographs was that grains became smaller and their shapes more regular. Using ultra sound solidification α Al appeared during ultrasound treatment the eutectic solidification time was longest around 10% compared with same condition experiment without ultrasound treatment.

Keywords: Ultrasonic vibration, Sono-solidification, Al-Si alloys, Grains size, Solidification temperature

1. Introduction

Increasing mechanical properties of aluminum alloys, decreasing costs of production, and improving the quality of recycled aluminum alloys is of great importance. Aluminum alloys have become an important material due to their low weight and good corrosion resistance. Weight is a most important parameter for vehicles as it is inversely proportional to fuel efficiency. One method for reducing weight is ultrasound radiation during solidification to enhance grain refinement of aluminum alloy microstructures. This ultrasound treatment can decrease grains size and increase mechanical properties. Improvement in wet ability by ultrasound vibration is closely related to grain refinement. Ultrasound treatment also benefits modifying and changing aluminum structures. Sono-solidification during solidification can decreased grain size and make aluminum structure more homogenous. The appearance of α -Al grains is

understood through acoustic cavitation: Ultrasound in molten Al-Si alloys exhibits two outstanding behaviors of cavitation, bubbling and acoustic streaming. First, the de-coupled eutectic reaction, which is recognized in the solidified eutectic Al-Si alloy with severe stirring, causes divorced α -Al grains by acoustic streaming with cavitation. Second, it is expected that high pressure of over 1 GPa generated by the collapse of cavitation bubbles leads to not only an increase in the eutectic temperature but also to higher silicon content at the eutectic point in the Al-Si alloy. Consequently, non-equilibrium α -Al grains are nucleated at collapsed cavitation bubble sites and are characterized by higher silicon content compared with that of primary α -Al grains in hypoeutectic Al-7mass%Si alloy [1, 3, 5].

2. Experimental procedures

Molten aluminum alloys were treated during solidification by ultrasound vibration with input power vibration of 2000W, peak-to-peak amplitude of 20 μ m, and resonant frequency of 20 kHz. Pouring temperatures were: 640°C for Al 7(wt)%Si, 625°C for Al 10(wt)%Si, 610°C for Al 12.6 (wt) %Si, 660°C for Al 14.5 (wt) %Si and 690°C for Al 17 (wt) %Si. The molten aluminum alloys was vibrated from the onset of pouring to one minute around the eutectic temperature 577°C. Billet temperatures during solidification were saving by computer, with the temperature sensor positioned 40 mm from the top of the crucible. Before pouring, metal was degassed by argon gas for 15 minutes, and the flow rate was 1.5 liters per minute. The preheating temperature of the containers was 300°C. The same procedures were used for control samples (A), with the only difference being that they were not vibrated. Aluminum was pouring to containers and cooled to room temperature. After the experiment, billets were cut vertically into two halves; small samples were then cut and polished before investigation by optical microscope. Our experimental equipment is shown in Figure 1.

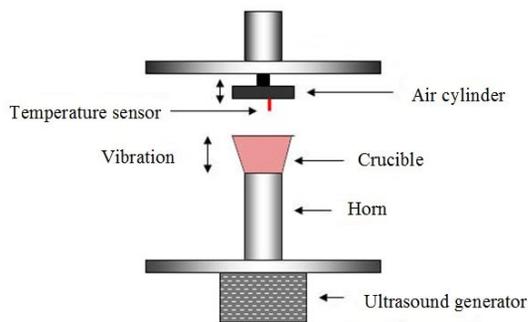


Fig. 1. Experimental equipment for sono-solidification

3. Results and discussion

A few parameters played important roles during experiments. First were the pouring temperature and the ultrasonic treatment time. Figure 2 shows typical microstructures of Al-Si. Figures 2(A) were taken after standard solidification without ultrasound vibration; Figures 2(B) were taken after solidification with ultrasound treatment.

Figure 2 shows Al microstructures as white areas and silicon as dark. Those shown in (B), following ultrasound treatment, indicate that the silicon has become smaller and more regularly oval shaped. The eutectic Si particles are only affected by the ultrasonic treatment when the treatment continues to semi-solid state during the eutectic reaction. In this case, the needle-like Si converts to a more compact form, one very useful for mechanical properties, due to vibration. Well-refined primary silicon grains are also crystallized close to the liquid's temperature of 660°C, allowing sono-solidification with acoustic cavitation to promote nucleation and restrain silicon growth and silicon grain destruction, thus achieving fine granular primary silicon. Although the equilibrium microstructure is composed of primary

silicon and eutectic, the eutectic area decreases due to the crystallization of non-equilibrium α -Al grains in the sono-solidification as well as an increase in primary silicon [1].

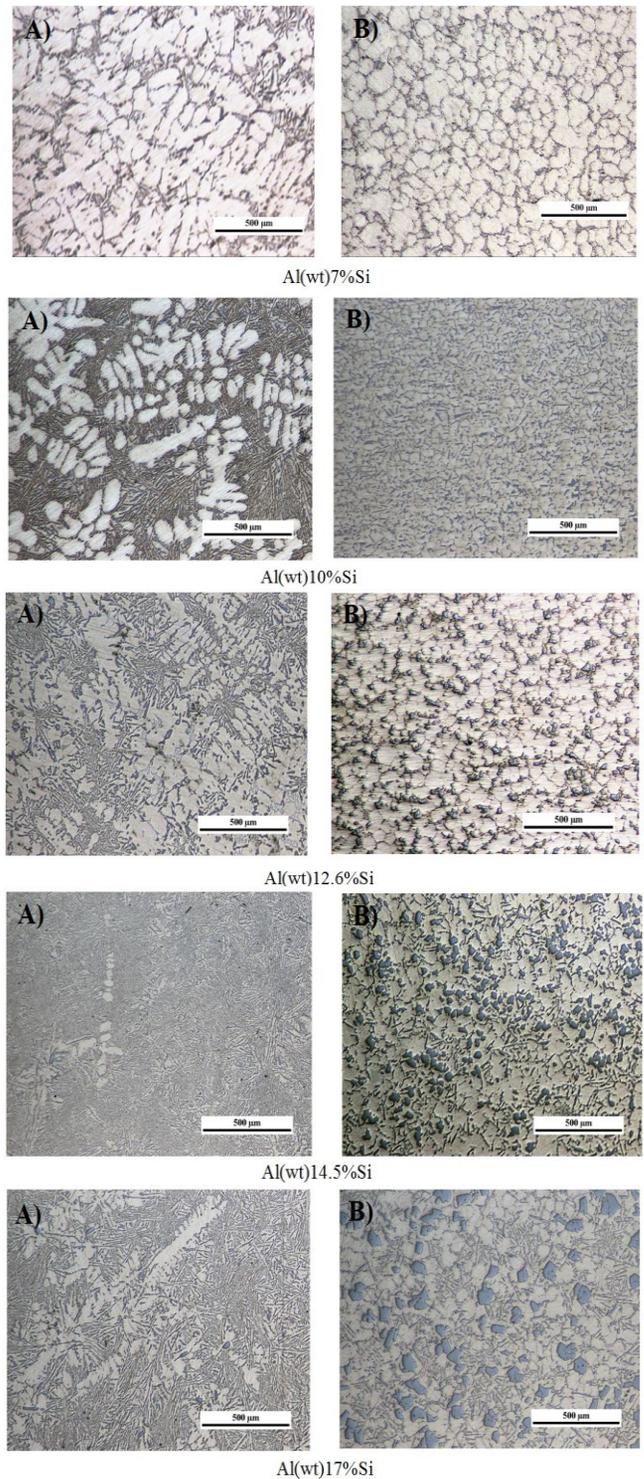


Fig. 2. Typical microstructures photographs without (A) and with (B) ultrasound treatments

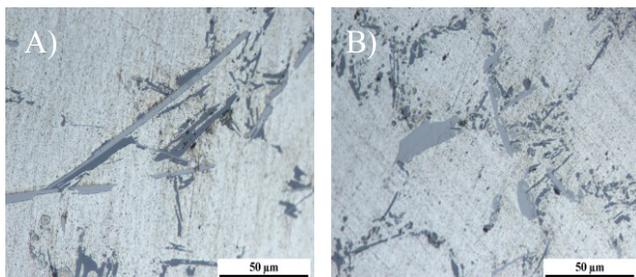


Fig. 3. Aluminum alloy with Fe compound without (A) and with (B) ultrasound treatment

Ultrasound treatment may also be good method of recycling of aluminum alloys. Generally recycle aluminum alloys include excessive amounts of iron (Fe) compounds. Iron's structure is long and needle-shaped and greatly affects mechanical properties of aluminum alloys. High Fe levels cause Fe intermetallic compounds to be in their primary phases in respective alloys, or crystallize at high temperature during solidification. A beneficial effect after sono-solidification was the appearance of α -Al. During ultrasound treatment, the eutectic solidification time grew about 10% longer compared with that without ultrasound treatment. It is worth mentioning here that a similar effect was observed with mechanical vibrations by Omura et al. (2009), who reported that the cooling rate of melt increased by imposition of mechanical vibrations, and this effect increased with increasing the vibration frequency [9]. It is believed that the acoustic streaming, which homogenizes the melt temperature, and enhances the convective heat transfer at the mold wall, plays a role in this effect [6-8]. Eskin (1998) showed that the ultrasonic intensity is directly related to the amplitude of waves by a square law. Thus, increasing the amplitude of vibrations leads to a substantial increase in intensity. With increased intensity, the severity of acoustic cavitations and streaming increases, and thus, a more pronounced effect can be obtained (2). Figure 3 (A) shows aluminum alloy with Fe compound; the Fe shape is long (around 200 μ m) and thin. Figure 3 (B) shows the same aluminum alloy after ultrasound treatment during solidification. The iron shape became smaller (around 20-30 μ m) and more regular. Figure 4 (A) shows a chart of typical cooling of Al(wt)7%Si without ultrasound treatment during solidification. The time from pouring to completed solidification was 310 seconds. The highest temperature was 619°C. Figure 4 (B) presents a solidification cooling chart with ultrasound treatment. The highest temperature was 621°C, with time from pouring to completed solidification of 345 seconds, about 10% longer.

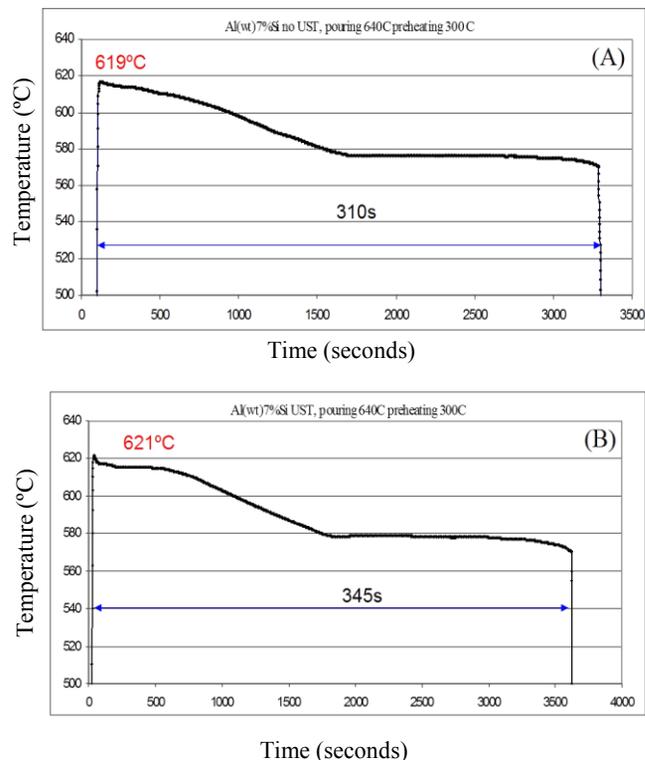


Fig. 4. Cooling chart, without (A) and with (B) sono-solidification treatment

The increasing of cooling temperature and increasing of solidification time costs by cavitation effect during ultrasound generation. A similar effect was observed during experiments with aluminum alloys with different weight percentages of silicone content.

Another phenomenon, an increase in the primary silicone area, was observed after sono-solidification.

Table 1.

Theoretical amount of primary silicone and after UST amount of primary silicon

12.6wt % Si UST	14.5wt % Si UST	17wt % Si UST
Theoretical primary Si value	Theoretical primary Si value	Theoretical primary Si value
0%	2.1%	5%
Average primary area Si after UST	Average primary area Si after UST	Average primary area Si after UST
6.3%	10.1 %	13.4%

Table 1 presents data regarding an increase in the primary silicone compact after ultrasound treatment. Aluminum alloy Al 12.6wt% Si does not include primary silicone at all, but when ultrasound treatment was used during solidification, 6.3 area % primary silicone was measured. In the case of 14.5wt% silicone compound after ultrasound treatment, the primary silicone area increased from 2.1 area % to 10.1 area %. Finally, the value primary silicone of the 17wt% Si aluminum alloy after ultrasound treatment increased to 13.4 area %.

4. Conclusion

1. Solidification with ultrasound treatment changes the shape and size of aluminum compositions, with grains becoming smaller and shapes more regular.
2. Non-equilibrium α -Al grains contain higher content than primary α -Al grains of hypoeutectic Al-Si alloy solidification without ultrasound treatment.
3. Solidification time during ultrasound treatment grew about 10% longer.
4. Ultrasound treatment during solidification improves mechanical properties of aluminum alloys.
5. The ultrasonic melt treatment was very effective in converting the long plate-like Fe inter-metallic phases, with Fe needles becoming a few times smaller and more regularly shaped.
6. Using ultrasound generator during solidification causes the primary silicon value to increase a few times.
7. Nucleation under cooling at the start of solidification was lowered by ultrasonic treatment.

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