Light Metals 2011 *Edited by: Stephen J. Lindsay*
TMS (The Minerals, Metals & Materials Society), 2011

EFFECT OF MECHANICAL VIBRATIONS ON MICROSTRUCTURE REFINEMENT OF Al-7 MASS% Si ALLOYS

Takuya Tamura[1], Toshiro Matsuki[2] and Kenji Miwa[1]
[1]Materials Research Institute for Sustainable Development, National Institute of Advanced Industrial Science and Technology (AIST), Nagoya 463-8560, Japan.
[2]Yamagata Research Institute of Technology, Yamagata 990-2473, Japan

Keywords: Mechanical vibration, Microstructure, Refinement, Solidification

Abstract

Mechanical vibration treatment is known to induce microstructure refinement. However, it is not completely understood which factor of vibrations is important for microstructure refinement. Factors of vibrations include frequency, acceleration, velocity and amplitude. In our study, it was found that velocity of mechanical vibrations, namely, the energy of vibrations is important factor for primary crystals refinement. This study aims to investigate effects of casting conditions with the mechanical vibrations on microstructure refinement of Al-7mass%Si alloys. Free space area for vibrating the melt affects the microstructure refinement. Moreover, primary crystal particles become rosette-like and fine when the mechanical vibrations are applied to the melt from about 923 K to 888 K (liquidus − 2 K). Thus, it was found that the mechanical vibrations promote heterogeneous nucleation just under the liquidus temperature.

Introduction

Al-Si alloy system is the most common system among the casting aluminum alloys. Controlling the structure of the alloys in the casting is an important factor about the foundry industries. Especially microstructure refinement is one of the most important factors. Thus, various methods have been developed for microstructure refinement. Among these methods, there is application of vibrations such as electromagnetic vibrations [1, 2], ultrasonic waves [3] and mechanical vibrations [4-7]. Especially, application of the mechanical vibrations attracts attention because of a simple system [8, 9]. Most researches about the effect of the vibrations mentioned that the size of primary dendrite particles was decreased by the vibrations imposed during solidification and finally globular particles were formed with increase in vibration intensity. However, it is not completely understood which factor of vibrations is important for microstructure refinement. Factors of vibrations are frequency, acceleration, velocity and amplitude. In the sine wave, two equations hold.

$$V = 2\pi fD \tag{1}$$

$$A = 2\pi fV \tag{2}$$

where D (m(0-p)) is amplitude (0-to-peak value), V (m/s(0-p)) is velocity (0-to-peak value), A (m/s^2(0-p)) is acceleration (0-to-peak value) and f (Hz) is frequency of the vibration wave. From these two equations, it is found that when two factors are decided, other two factors are decided automatically. The frequency has the different character from other factors, because other factors have waveform. Thus, the frequency and one of other three factors (acceleration, velocity and amplitude) have to be considered as the vibration parameters when the vibrations are applied during solidification in order to refine the microstructure. The authors reported that the velocity of mechanical vibrations was found to be important factor for primary crystals refinement [10]. It is known that vibration energy of the simple harmonic oscillation (sine wave vibration) can be described as follows.

$$E = \frac{1}{2}mV^2 \tag{3}$$

where E (J) is vibration energy, m (kg) is mass of vibration object and V (m/s(0-p)) is velocity of the vibration wave. Thus, the square of the velocity corresponds to the vibration energy. Thus, it was found that the energy of mechanical vibrations promotes microstructure refinement during solidification. In this study, the effects of casting conditions with the mechanical vibrations on microstructure refinement of Al-7 mass% Si alloys were studied.

Experimental Procedures

Hypo-eutectic Al-7 mass% Si alloys were prepared by using pure aluminum (99.9 %) and Al-24.3 mass% Si master alloys. From cooling curves, the eutectic and liquidus temperatures were found to be 850 K and 890 K, respectively. Iron was found to be contained about 0.5 mass% by ICP analysis. Specimens with weight of about 26~29 g were obtained from the prepared Al-7 mass% Si alloys. The specimen was inserted to an alumina crucible (30 mm in outer diameter, 24 mm in inner diameter and 80 mm in height), and the alumina crucible was sealed with a ceramic cap, as shown in Fig. 1.

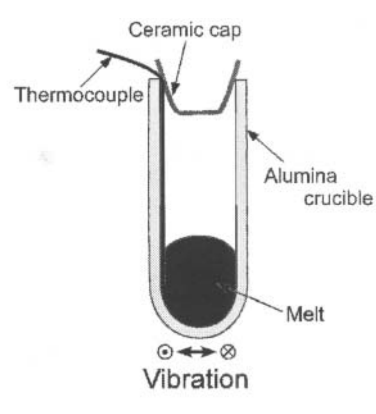

Figure 1. Schematic illustration of the alumina crucible where the molten specimen was put in.

Temperature of the specimen was measured by a K-type thermocouple that was inserted 65 mm from the top of the crucible to the side of the specimen. The crucible which was set as shown in Fig. 1 was inserted into an electric furnace. The specimen was heated up to 923 K and held for 5 min. Then, the crucible where the molten specimen was put in was taken out from the furnace, and clamped by an air cylinder to a vibration testing machine. This vibration testing machine can impose sine wave vibration with given frequency and given acceleration. The vibration direction is shown in Fig. 1. The mechanical vibration was applied to the melt in the crucible from about 923K to 863K, and the crucible was quenched in water at 863K. Values of the acceleration and the velocity were described by 0-to-peak value. However, values of the amplitude were described by general peak-to-peak value. Microstructure of the solidified specimen was observed by optical microscopy after etching.

Results and discussion

Effect of free space area for vibrations on microstructure

Figure 2 shows microstructures in the specimens solidified during imposition of the mechanical vibrations with same frequency. The frequency is 50 Hz. The specimen for 87.8 mm/s shown in (a) consists of large dendritic primary particles. Size of the primary particles was decreased with increase in the velocity. And the specimen for 702 mm/s shown in (d) consists of small rosette-like primary particles. Moreover, it was found that the microstructures didn't change even if frequency varied 8 times [10]. However, the microstructure refinement by the vibrations with high amplitude or high acceleration was affected by the frequency [10]. Thus, it was found that the velocity of mechanical vibrations, namely, the energy of vibrations is important factor for primary crystals refinement.

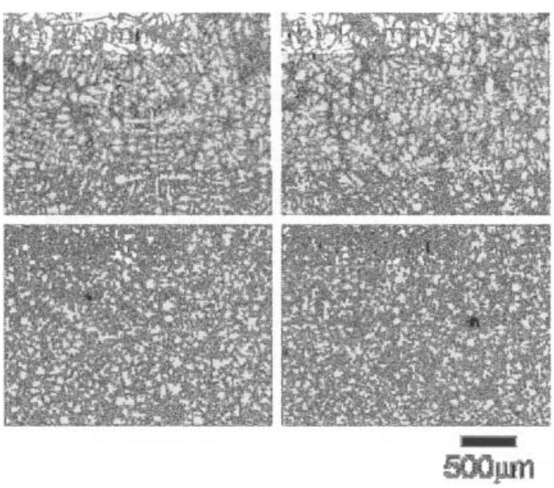

Figure 2. Microstructures in the specimens solidified during imposition of the vibrations with same frequency 50 Hz.

However, casting conditions which affect the microstructure refinement by the mechanical vibrations exist with the exception of these 4 vibration factors. For example, free space area for the melt with the mechanical vibrations is. When a permanent mold with risers is used, it is energy-saving that important part of the mold vibrates by a mechanical vibrator because permanent molds are heavy [8, 9]. In this situation, the melt movement is limited. Thus, effects of the free space area for the melt with the mechanical vibrations on the microstructure were studied. Schematic illustration of the alumina crucible shown in Fig. 1 has the free space area for the melt with the mechanical vibrations because the alumina crucible was sealed with the ceramic cap. However for schematic illustration of the alumina crucible shown in Fig. 3, there is no free space area for the melt with the mechanical vibrations because the melt was locked by a carbon block which was fixed to the alumina crucible.

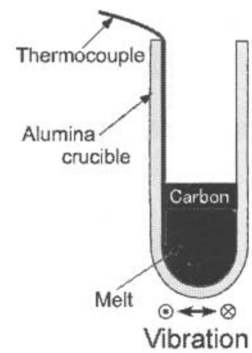

Figure 3. Schematic illustration of the alumina crucible. The melt is locked by a carbon block which was fixed to the crucible.

Figure 4 shows microstructures in the specimens solidified during imposition of the mechanical vibrations. The frequency and the velocity are 50 Hz and 702 mm/s, respectively. The specimen shown in Fig. 4(a) was solidified in the alumina crucible shown in Fig. 1. And the specimen shown in Fig. 4(b) was solidified in the alumina crucible shown in Fig. 3. The specimen solidified during imposition of the mechanical vibrations with free space area shown in Fig. 4(a) consists of small rosette-like primary particles. However, the specimen solidified during imposition of the mechanical vibrations without free space area shown in Fig. 4(b) consists of dendritic primary particles that are similar to those shown in Fig. 2 (b). The specimen shown in Fig. 2 (b) was solidified during imposition of the mechanical vibrations with weak velocity in the alumina crucible shown in Fig. 1. Thus, it was found that the effect of the mechanical vibrations on the microstructure weakens when the melt cannot vibrate freely. From these results, it can be presumed that the mechanical vibrations with higher energy are needed in order to refine the microstructures when a permanent mold with risers is used.

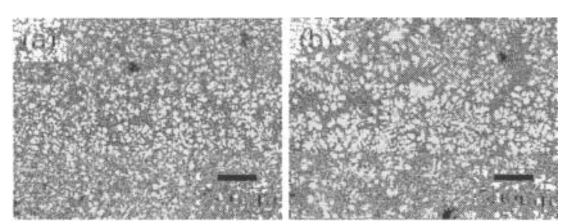

Figure 4. Microstructures in the specimens solidified during imposition of the mechanical vibrations (50 Hz, 702 mm/s); (a): in the alumina crucible shown in Fig. 1; (b): in the alumina crucible shown in Fig. 3.

Effect of imposition temperature region on microstructure

It is important casting condition that the primary particles were refined in a certain temperature range. Thus, effects of the end temperature of the mechanical vibrations on the microstructure were studied. However, a cooling rate in the liquid state for the specimen solidified during imposition of the mechanical vibrations (50 Hz, 702 mm/s) shown in Fig. 2 (d) is about -3 K/s. This cooling rate was too fast to control the end temperature of the mechanical vibrations accurately. Thus, the alumina crucible shown in Fig. 1 was covered with heat-insulating ceramic boards in order to decrease the cooling rate. The cooling rate in the liquid state for the specimen solidified during imposition of the mechanical vibrations (40 Hz, 702 mm/s) became about -0.2 K/s by heat-insulating ceramic boards. Figure 5 shows cooling curves for the specimens solidified during imposition of the mechanical vibrations with the frequency of 40 Hz and the velocity of 702 mm/s. The end temperature of the mechanical vibrations was varied. The specimen without the mechanical vibrations and the specimen on which the mechanical vibrations were imposed up to 892 K (liquidus + 2 K) showed the supercooling. However, the specimen on which the mechanical vibrations were imposed up to 863 K and the specimen on which the mechanical vibrations were imposed up to 888 K (liquidus – 2 K) didn't show the supercooling.

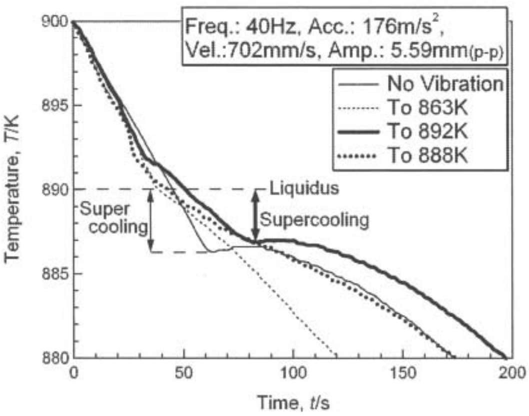

Figure 5. Cooling curves for the specimens solidified during imposition of the mechanical vibrations (40 Hz, 702 mm/s). The end temperature of the mechanical vibrations was varied.

Figure 6 shows microstructures in the specimens solidified during imposition of the mechanical vibrations with the frequency of 40 Hz and the velocity of 702 mm/s. The end temperature of the mechanical vibrations was varied and these microstructures correspond to the cooling curves shown in Fig. 5. The specimen shown in (a) was solidified without the mechanical vibrations. The specimen consists of large dendritic primary particles. Moreover, the specimen on which the mechanical vibrations were imposed up to 892 K (liquidus + 2 K) shown in (c) consists of large dendritic primary particles that are similar to those without the vibrations. These two specimens showed the supercooling. On the other hand, the specimen on which the mechanical vibrations were imposed up to 863 K shown in (b) consists of small rosette-like primary particles. Moreover, the specimen on which the mechanical vibrations were imposed up to 892 K (liquidus - 2 K) shown in (d) consists of small rosette-like primary particles. However, size of the primary particles was larger than that shown in (b). The cooling rate for the specimen on which the mechanical vibrations were imposed up to 863 K was faster than those for other specimens on which the mechanical vibrations were not imposed in the semisolid region. Thus, it is considered that the rosette-like primary particles grew larger before water quenching at 863 K for the specimen on which the mechanical vibrations were imposed up to 892 K (liquidus - 2 K) shown in (d). As a result, important temperature region was found to be just under the liquidus temperature for primary crystals refinement by the mechanical vibrations. When heterogeneous nucleation just under the liquidus temperature is promoted, the supercooling is considered to disappear. Thus, it was found that the mechanical vibrations promote heterogeneous nucleation just under the liquidus temperature.

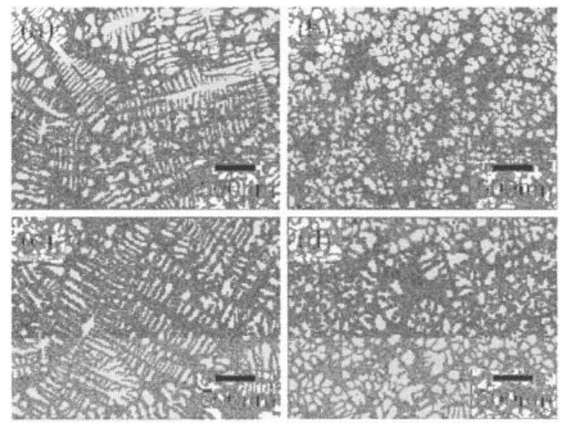

Figure6. Microstructures which correspond to the cooling curves shown in Fig. 5. The end temperatures of the vibrations were; (a): no vibration, (b): 863 K, (c): 892 K, (d): 888 K.

Conclusions

The effects of casting conditions with the mechanical vibrations on microstructure refinement of Al-7 mass% Si alloys have been investigated, and the following conclusions have been derived.

It was found that free space area for vibrating the melt affects the microstructure refinement. The effect of the mechanical vibrations on the microstructure weakens when the melt cannot vibrate freely.

The primary crystal particles become rosette-like and fine when the mechanical vibrations are applied to the melt from about 923K to 888K (liquidus - 2K). Thus, it was found that the mechanical vibrations promote heterogeneous nucleation just under the liquidus temperature.

Acknowledgments

The authors thank Mrs. T. Yamaguchi for technical assistance.

References

1. A. Radjai and K. Miwa, Metall. Mater. Trans. A31 (2000), pp. 755-762.
2. Y. Mizutani, Y. Ohura, K. Miwa, K. Yasue, T. Tamura and Y. Sakaguchi, Mater. Trans. 45 (2004), pp. 1944-1948.
3. W. Khalifa, Y. Tsunekawa and M. Okumiya, Int. J. Cast. Met. Res. 21 (2008), pp. 129-134.
4. S. Wu, L. Xie, J. Zhao and H. Nakae, Scripta Materialia 58 (2008), pp. 556-559.

5. F. Taghavi, H. Saghafian and Y.H.K. Kharrazi, Materials and Design 30 (2009), pp. 115-121.
6. F. Taghavi, H. Saghafian and Y.H.K. Kharrazi, Materials and Design 30 (2009), pp. 1604-1611.
7. C. Limmaneevichitr, S. Pongananpanya and J. Kajornchaiyakul, Materials and Design 30 (2009), pp. 3925-3930.
8. N. Omura, Y. Murakami, M. Li, T. Tamura, K. Miwa, H. Furukawa, M. Harada and M. Yokoi, Mater. Trans. 50 (2009), pp. 2578-2583.
9. N. Omura, Y. Murakami, M. Li, T. Tamura, K. Miwa, H. Furukawa, M. Harada, Mater. Trans. 50 (2009), pp. 2604-2608.
10. T. Tamura, T Matsuki, K Miwa, Proceedings of the 12th International Conference on Aluminium Alloys (2010), pp. 658-662.