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Stable levitation of the Metallic Melt by Simultaneous Imposition of Alternative and High Static Magnetic Field

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ABSTRACT

This paper presents a levitation technique using the static and the alternating magnetic fields. The levitation was done by simultaneous imposition of an alternating magnetic field and a high static magnetic field (max 10T). The appearance of specimen was observed by a high-speed video camera, and temperature was measured by a pyrometer. The observation of the levitated melt by the simultaneous imposition indicated that the melt was stably levitated like a hard sphere when intensity of the static magnetic field was more than 2T. The stable levitation did not affect the nucleation from the undercooled melt but significantly affected the solidified structure from the undercooled melt.

Key words: levitation, convection, oscillation, undercooling

INTRODUCTION

Containerless processing has great advantages for research on fundamentals of solidification and for materials processing [1][2]. In the melt that does not contacts with crucibles and molds, the heterogeneous nucleation and the contamination from the crucible are avoided significantly. The suppression of the heterogeneous nucleation leads to the highly undercooled state, in which amorphous alloys, metastable phases and grain-refined structure are expected to be obtained. Thus, the containerless processing is paid attention into from fundamental and engineering aspects. This paper presents a levitation technique using the alternating and the static magnetic fields. The effect of the simultaneous imposition of the alternating and the static magnetic fields on the stability and the solidification behavior are discussed.

LEVITATION METHODS USING THE MAGNETIC FIELDS

There are several methods to levitate the melt. A conventional method is the electromagnetic levitation method in which the melt was levitated by the alternating magnetic fields with high frequencies. This method has been used to measure the physical properties of the melt [3]. Alternating magnetic fields induces the lift force and supplied thermal energy. The electromagnetic force due to the alternating magnetic field is generally expressed by

$$F = \frac{1}{\mu}(B \cdot \nabla)B - \frac{1}{2\mu}\nabla(B \cdot B) \quad (1)$$

The first term is called the rotational term causing the electromagnetic stirring and the second term the non-rotational term cause the levitation force against the gravitational force. With increasing frequency of the alternating magnetic field, the second term becomes dominant. However, the first term still affects dynamics of the levitated melt. Thus, this method intrinsically induces the violent vibration and strong convection inside the melt. These phenomena may cause instability of the levitated melt. Furthermore, there is uncertainty on understanding effect of the convection or the stirring on the nucleation and solidification.

An alternative levitation method using the static magnetic field has been reported [4][5][6]. In this method, the magnetization force due to the magnetic field gradient is expressed by following equation.

$$F = \chi H(\partial H/\partial z) = -\frac{1}{2}\chi \nabla H^2 \quad (2)$$

The magnetization force is a body force as well as the gravitational force. The levitated melt by the static magnetic field has advantages to avoid the violent vibration and the strong convection. However, the Cu-based alloys used in the present study, exhibit rather small magnetic susceptibility and the magnetization force can be negligible when the experimental apparatus for the present study was used.

Another levitation method using both of the alternating and the static magnetic fields has been proposed [7][8]. In this method, the alternating magnetic field causes the lift force, as well as the conventional methods. Thermal energy is also supplied by the alternating method. The imposed static magnetic field does not affect the lift force and the thermal energy transfer, but significantly reduces the convection in the melt. Consequently, it is expected that the melt is stably levitated without convection.

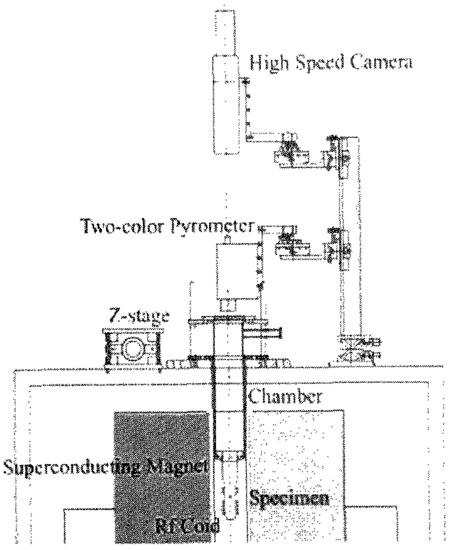

Figure 1. Levitation apparatus under the alternating and the static magnetic fields.

EXPERIMENTAL PROCEDURS

Figure 1 shows the experimental apparatus to levitate a melt droplet by the simultaneous imposition of alternating and static magnetic fields. The static magnetic field is imposed by a cryogen-free superconducting magnet. This magnet has 100mm bore and imposes magnetic field up to 10T at room temperature. Two chambers are inserted to the magnet. One of the chamber made of copper is used to sheild the supercoducting coil from the alternating magnetic field. The other is a vacuum chamber. The levitated melt was placed at the maximum point of the static magnetic field in the bore. He-H_2 gas was used to solidify the levitated melt.

The specimen used in the present study is Pure Cu and Cu-1at%Ag. The Diameter is about 5mm, and the weight is about 1g. The motion of the molten metal is observed by High speed CCD camera, and the temperature is measured by using a two-color pyrometer.

RESULTS AND DISCUSSION

Top view of the levitated melt by high speed camera is shown in Fig.2. Interval between the pictures is 1/125 sec. The melt droplet violently vibrated at a magnetic field of 0T. As the intensity of the magnetic field increased, the oscillation and the convection of the melt was reduced. At a magnetic field of 10T, the violently vibration and oscillation were not observed. Only the rotation which axis is parallel to the static magnetic field is observed. The levitated melt looks like a hard sphere in this condition.

Figure 3 shows area change of cross section of the levitated melt for the static magnetic field of 0, 0.1, 0.5, and 10T. Under 0T, cross section was fluctuated due to the convection. The imposition of 0.1T slightly reduced the temperature fluctuation, but the convection still remained. The temperature fluctuation was almost suppressed at a magnetic field of 0.5T. The fluctuation observed by the pyrometer was completely reduced at magnetic fields more than 1T.

Frequency spectra of the cross sectional area change,

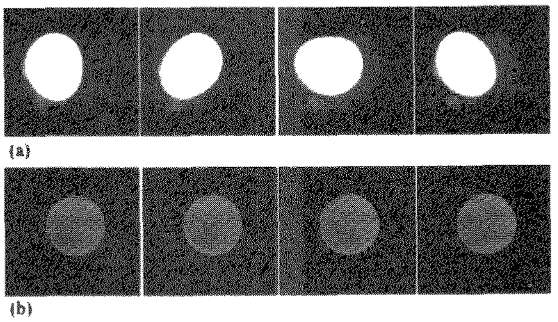

Figure 2. Top view of the levitated Pure Cu melt. (a) 0T and (b) 10T. ΔT=1/125 sec.

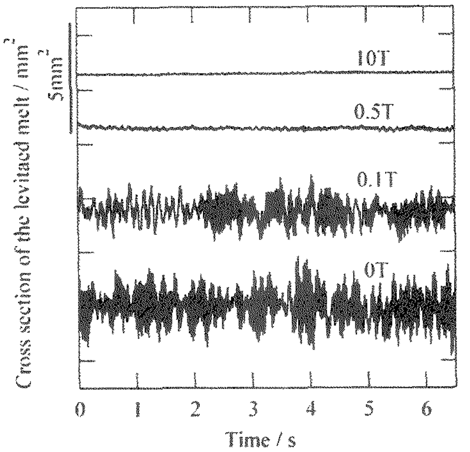

Figure 3. Cross section change of the levitated melt.

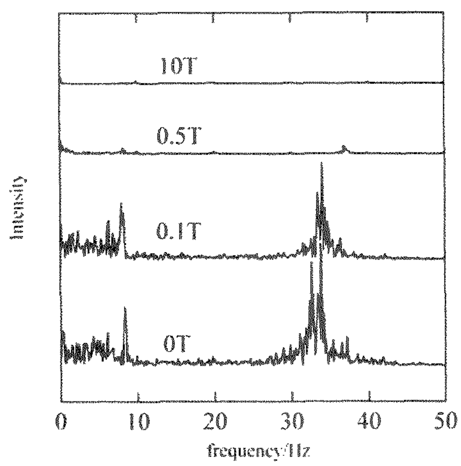

Figure 4. Fourier transformation of the cross section change.

which is obtained by the Fourier transformation, are shown in Fig.4. In the case of 0T, peaks are observed at around 7Hz and 34Hz. The former peaks are related to the movement of the center of gravity. The later one corresponds to the oscillation of the levitated melt, which are determined by the surface tension of the melt [3]. As the static magnetic filed increases up to 0.1T, the peaks tended to be clearly observed. At a magnetic field of 0.5T, only a peak was detected for each frequency range (7 and 34Hz). No peak was detected when the static magnetic

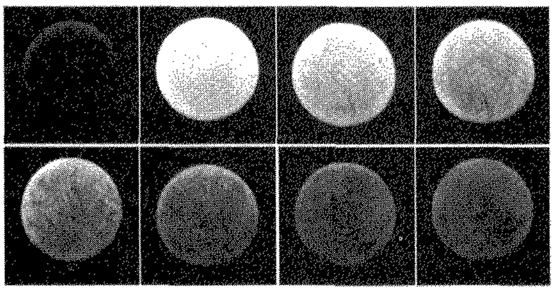

Figure 5. Sequence photographs of the recalescence and the dendritic growth in the Cu-1at%Ag alloy.

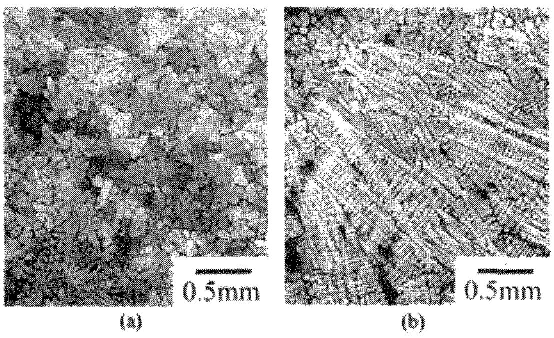

Figure 6. Solidified structure of the levitated Cu-1at%Ag alloys.(a) 0T and (b) 10T.

field was more than 1T, indicating that the levitated melt was statically and stably levitated.

It is interesting to investigate the effect of the static magnetic field on the nucleation behavior and on the solidified structure from the undercooled melt. Figure 5 shows sequence photographs of the solidification from the undercooled state at a magnetic field of 10T. Interval between the pictures is 3/250 sec. The recalescence is clearly recognized, since brightness of the levitated specimen suddenly increased. After detecting the beginning of the recalescence, dendrites are observed on the surface of the melt. The solidification structures are shown in Fig.6. In the case of 0T, the columnar grain region was restricted near the surface area. In the central part of the solidified specimen, the equiaxed grains were observed. On the other hand, the columnar grains continuously grew from the surface to the center. The reduction of convection in the levitated melt significantly affected the solidified structure. The result suggests that not only the nucleation but also convection contributes to the equiaxed grain formation.

CONCLUSION

This paper examines the levitation technique using the static and the alternating magnetic fields. The simultaneous imposition of the static magnetic field reduces the oscillation, the convection in the melt and the movement of the center of gravity. Consequently, the temperature fluctuation is significantly reduced and the stable levitation is achieved. The melt levitated without the oscillation and the convection will provide new knowledge on the nucleation and the solidification from the undercooled melt.

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