Experimental Determination of Velocity Flow Fields in a Cold Model for Czochralski Crystal Growth System Using an Incorporated Magnet Probe

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Abstract: An experimental investigation on flow pattern was carried out in molten Woods metal using an incorporated magnet probe to determine the velocity field in a Woods metal model of Czochralski crystal growth system. The local velocities in Woods metal were obtained 3-dimensionally at numerous positions of large crucible by measuring the voltage induced in the melt. Since there have not been a lot of the model experiments on the velocity distributions in the large size of melt with low Prandtl number for Czochralski crystal growth system, the present paper aims to give useful guidelines for the analysis of fluid flow in Czochralski growth system.

1. Introduction

Czochralski method is the most frequently used technique to grow crystals from the melt. In the transport mechanism existing in the melt of CZ crystal growing system, oxygen transfer is occurred by convection or diffusion and heat transfer is occurred by convection or conduction. From these facts it is known that convective transport is dominant, so convection in the melt is very important. Especially, as the convective transport becomes more and more dominant with the increase of melt size, importance of the study on the convection has been also increased. For this reason, many researchers have tried to measure the local velocities in the study on convection.

The measurement of the velocity in the CZ melt is mainly divided into two categories. One is the measurement in the melt of the high Prandtl number. The Measurement in the transparent fluid such as silicone oil using photocamera is included to this category[1]. However the flow mode in the high Prandl number melt is different from that of the silicon melt because of large difference in the value of Prandl number between transparent fluid and the molten silicon.

The other is direct measurements in the real silicon melt of low Prandtl number using X-ray radiography[2]. The measurement technique using tracer is included to this category. But this technique is limited to small size of silicon melt because the movement of tracer in large silicon melt nearly cannot be observed due to the limitation in penetration of X-ray, From this reason, the observed flow in small silicon melt will be different from that of the large commercial silicon melt.

Referring to the experiment using tracer[2], even no crucible rotation the observed tracer trajectory in the silicon melt is randomlike and tracer is not confined to a specified plane or a point due to natural convection. Hence it is impossible to measure the local fluid velocity at the specified melt position where we want to measure.

In addition, In fact it is very difficult to perform an experiment in CZ system due to short life of velocity sensor at very high temperature of about 1410℃. Hence we adopt low melting point Woods metal of low Prandtl number similar to that of silicon as the working fluid in the present study, and adopt the incorporated magnet probe developed by Vives[3,4] as the velocity sensor for the local velocity measurement at the specified melt position where we want to measure.

2. Experiment

Local fluid velocity was measured at numerous positions of molten woods metal melt by immersing the incorporated magnet probes into the melt position where we want to measure.

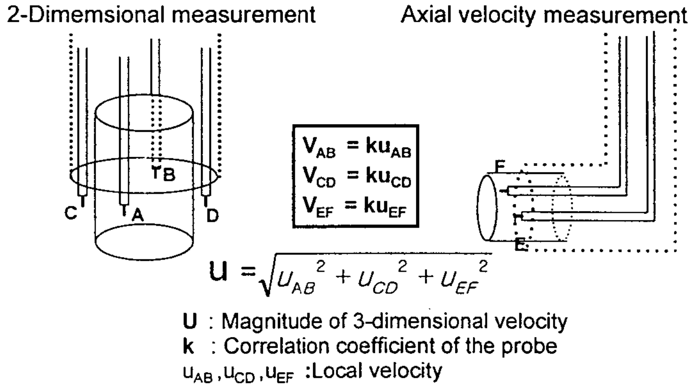

Fig. 1. The schematic diagram of velocity probes

Fig. 1 shows the schematic diagram of velocity probes used in the present study. Principle of velocity measurement is based on magnetohydrodynamics, which simply explains that conducting fluids moving within a magnetic field generates an electric field. Referring to Fig. 1, each potential difference between the electrodes is proportional to the magnitude of the velocity vector perpendicular to the line A-B, C-D and E-F respectively.

Schematic diagram of calibration apparatus is shown in Fig. 2. It is an annular type of circular cylinder.

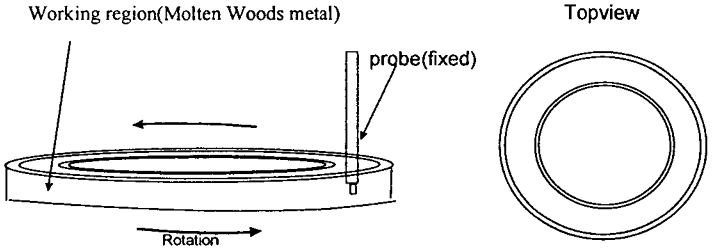

Fig. 2. Schematic diagram of calibration device

Local velocity measurement system is illustrated in Fig. 3. It is composed of several parts, which is a cylindrical vessel, a cylindrical model crystal kept at constant temperature, a turntable, a variable speed motor controlled by rotation rate controller, a cylindrical band heater equipped with PID(Proportional, Integral, Differential) type of temperature controller, velocity probes, K-type thermocouples. Here the cylindrical vessel containing molten Woods metal is mounted on a turntable, which is driven by the motor. In addition, computer based data acquisition system consisting of a personal computer and one data acquisition switch unit with multiplexer is prepared to provide simultaneous velocity and temperature measurements at numerous melt positions. The properties of Woods metal are given in Table1. [5]

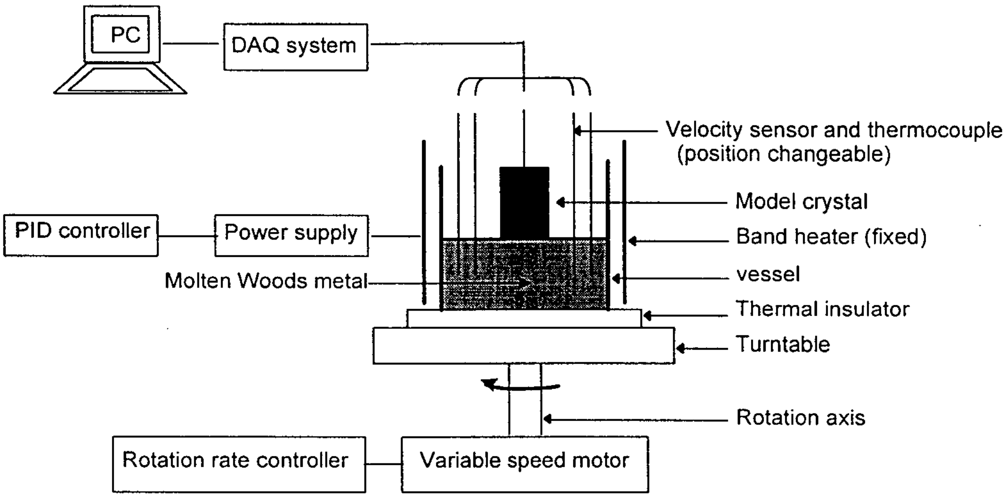

Fig. 3. Schematic diagram of local velocity measurement system

Table 1. Physical data of Woods metal used in the experiments.

Composition	50Bi-25Pb-12.5Sn-12.5Cd
Melting point	70^{o}C
Density	8.37×10^{3}kgm^{-3}
Specific heat	1.225×10^{2}J kg^{-1}K^{-1}
Electrical conductivity	$9.0 \times 10^{5}\Omega^{-1}$m^{-1}
Thermal expansion coefficient	1.0×10^{-4} K^{-1}
Thermal conductivity	1.405×10^{1} Jm^{-1}s^{-1}K^{-1}
Prandtl number	0.0197

3.Results and Discussion

3.1. Calibration of the velocity probe

If we can determine the so-called correlation coefficient of probe(**k**) that is same as the slope of velocity versus voltage plot, local velocity of fluid can be easily known from the measured voltage. Therefore calibration experiment was firstly carried out to determine the correlation coefficient. Due to the short width of working region of calibtration device in fig. 2, slip of Woods metal contained in the region is almost negligible. Thus local velocity of the fluid in the region is assumed to be identical to the rotation speed of turntable at the position where velocity probe places. The magnitude of the measured voltage was corresponded to the local velocity evaluated from the controlled rotation speed of turntable. The voltage output during 100 sec observation is displayed in fig. 4. We can see that the value of induced voltage increases as the rotation rate of turntable increases from 1rpm to 3rpm

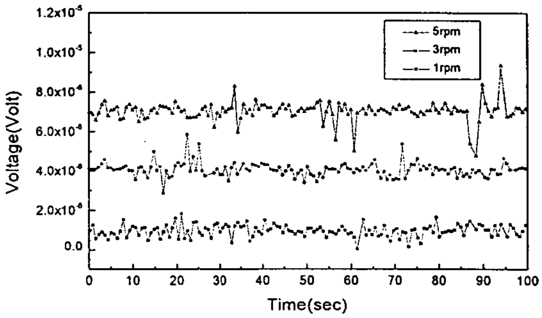

Fig. 4. Voltage output in calibration experiment

Fig. 5. represents the final calibration result. Each value of the voltage is obtained from the averaged value of voltage output in fig. 5. It is shown that voltage has linear relationship with local velocity for the wide range of 65mm/sec. The correlation coefficient of the probe in the present study is determined to be 0.154 μV/㎜ *via* least mean squares method.

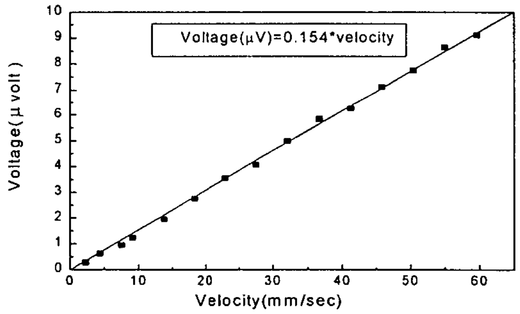

Fig. 5. Calibration results of the probe

3.2 Observation of the 3-dimensional velocity fields

Figure 1. which is previously referred shows how to measure the local velocity 3-dimensionally. Two types of velocity probes are prepared. One is for the 2-dimensinal velocity measurements and the other is for the axial velocity measurement. Each potential difference between the electrodes placed antipodally in the mid-plane of a cylindrical permanent magnet is proportional to the magnitude of the velocity vector perpendicular to the line A-B and line C-D respectively. Thus two velocity components of fluid can be measured simultaneously and by placing one more probe as in Fig. 1 at the same melt position for the axial velocity measurement, finally 3-dimensional velocity measurement is possible.

Observation on the velocity field was made for the vessel rotation rate of 1rpm under the condition of temperature difference between the vessel wall and the model crystal of 35°C, and the vessel radius of 0.1m, melt height of 0.1m. Side view of the measured velocity vectors is shown in fig. 6. In general, fluid rises toward the free surface along the hot vertical walls of the vessel and after it moves toward the cold model crystal, it descends toward the bottom of vessel. This is occurred mainly by natural convection. We represent this result as a reference of numerical simulation[6]. It seems that there is a characteristic of slight asymmetry in the measured velocity field. Such an asymmetry is likely to arise from the effect of vessel rotation. However the correct reasons of those characteristics are not well known presently. Thus more experiments are required and other experiments at different boundary condition.

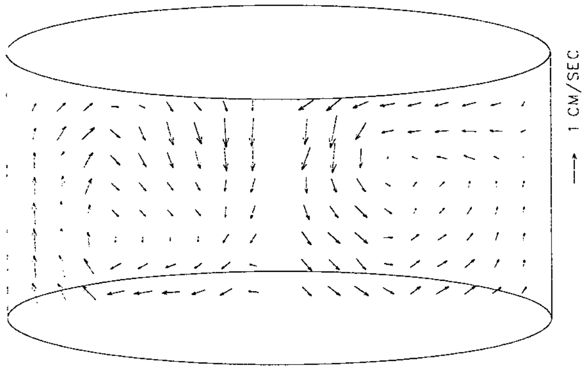

Fig. 6. Side view of the measured velocity vectors

4. Summary

Low melting point woods metal of low Prandtl number was adopted as the working fluid to simulate the flow in the melt of CZ crystal growing system, and incorporated magnet probes were introduced to measure the local velocity of the fluid 3-dimensionally in Woods metal melt. We determined the velocity fields in the melt successfully, and this result can be used as a reference of numerical study.

5. Acknowledgment

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6. References

[1] Ozoe, H,K. Toh and T.Inoue, *J. Crystal Growth*, 110, 472-480

[2] Kakimoto,K., M. Eguchi, H. Watanabe and T. Hibiya, *J. Crystal Growth*, 88, 365-370

[3] R.Ricou and C. Vives, *Int. J. Heat Mass Transfer*, 25, 1579 (1982).

[4] H.-C. Lee, J. W. Evans, and C. Vives, *Met. Trans.*, 15B, 734 (1984).]

[5] W. F. Hughes and F. J. Young: Electromagnetodynamics of fluids ,John Wiley & Sons, Inc., NY, (1966).

[6] M.C. Kim, K.-W. Yi , et al., *Matals & Materials 4, 89*(1998)