# INFLUENCE OF MOLTEN METAL FLOW ON THE CHARACTERISTICS OF INGOT CAST BY MOVING MOLD CASTING PROCESS

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**ABSTRACT** In order to investigate the influence of molten metal flow on the characteristics of ingot cast by moving mold casting process, water model experiments, numerical analysis and casting experiments were carried out. Casting experiments were made by simulator developed in this study. It is found that improvement of surface quality by moving mold casting, influence of nozzle shape on surface quality.

**Keyword:** *moving mold casting, aluminum alloy, fluid flow, surface quality.*

## 1.INTRODUCTION

Twin belt casting, block casting and twin roll casting process have been utilized during the past two decades as new near net shape casting process. They are called moving mold casting process generically.

In the moving mold casting process, the damage of ingot surface by friction with mold are considered to be small because relative speed between mold and ingot is equal to zero. So, the moving mold casting process has a potential of improving the surface quality of ingot compared with conventional casting process. So, many studies have been conducted about moving mold casting process[1-7], some studies about ingot surface quality[5]and about fluid flow are also found [6,7].

The focus of this study is clarifying the influence of molten metal flow on the characteristics of ingot. Experiments, water model experiments and casting experiments, and numerical analysis were carried out in this study. The experimental apparatus called moving mold casting simulator were developed to investigate moving mold casting process.

## 2. EXPERIMENT

### 2.1 Water model

#### 2.1.1 Experimental procedure

Homogeneous, laminar flow is needed for producing ingot which has good surface quality. Water model experiment were conducted to estimate the influences of nozzle construction and shape on molten metal flow. Schematic diagram of experimental apparatus of water model are shown in figure 1. It is consist of reservoir tank, pomp, flow meter, tundish, nozzle and mold part. Three types of nozzle were used in this experiments. They were named single slit type, separated slit type and parallel pipes type. Figure 2 shows schematic diagram of these nozzles. Nozzle with tapered tip, tapered face type, and without taper tip, flat face type, were both examined in single slit type nozzle. Flow observation was carried out by using video camera to record paths of dispersing tracer particle. So, pomp and flow meter were able to use for particle contained liquid. Polystyrene particle, 1060kg/m3 in density, were used as tracer.

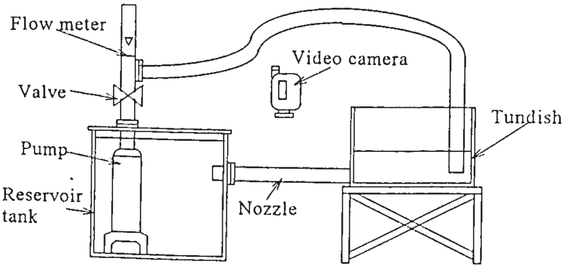



Fig. 1 Schematic diagram of apparatus for water model experiment

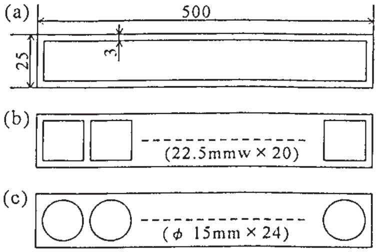



Fig. 2 Specification of nozzle (view from outlet of nozzle)
(a) Single slit nozzle,(b) Separated slit nozzle
(c) Parallel pipe nozzle

## 2.2 Casting experiment

### 2.2.1 Experimental apparatus

The simulator of moving mold casting were developed to investigate moving mold continuous casting process. Schematic diagram of simulator are shown in Figure 3. The simulator are consist in melting furnace, tundish, nozzle, upper and lower mold, side dam and mold driving unit. In the simulator lower mold and side dam are movable but upper mold are fixed to simplify the structure of apparatus. So, surface characteristics of ingot cast by moving mold casting process can estimate only in lower surface.

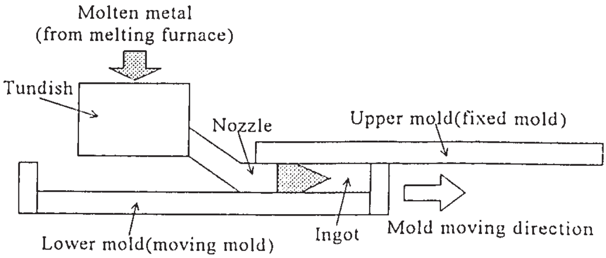



Fig. 3 Schematic diagram of simulator of moving mold casting

### 2.2.2 Experimental procedure

The present investigation has been conducted on 99.7% purity aluminum whose composition are listed in table 1. The experimental condition are listed in table 2.

Table 1 Typical composition of Aluminum alloy used in this work.

| Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | Al |
|---|---|---|---|---|---|---|---|---|
| 0.10 | 0.11 | <.005 | <.005 | <.005 | <.005 | <.005 | <.005 | Bal. |

Table 2 Experimental condition

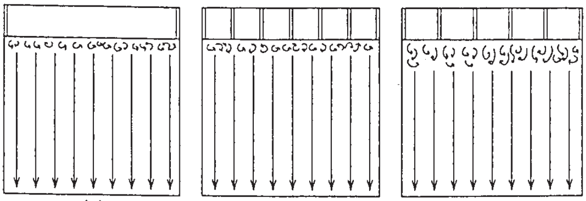
| | |
|---|---|
| Ingot size | 0.2 m in width, 0.06 m in thickness |
| Casting temperature | 973 K |
| Mold | Cu |
| Nozzle | graphite |
| Casting speed | 0.05 m/s |
| Mold moving length | 0.4 m |

Casting experiments were carried out in the procedure as shown below. Molten aluminum melted in electric furnace was poured into tundish of which outlet was closed by gate type stopper. Temperature of molten aluminum in tundish was measured by thermocouples. The time when measured temperature was became casting temperature, stopper was removed and molten aluminum was poured into mold. At the same time, moving mold started and stopped after mold was moving a fixed length. If timing of mold start was delayed to start pouring, molten metal flow was stagnant at the exit of nozzle. It causes blockade of nozzle in a high probability. And, it is supposed that solidified shell on a upper fixed mold influence molten metal flow or enclosed nozzle exit. To, minimize the possibility of turbulent flow and nozzle enclosing heat insulation sheet, main component is aluminum oxide, was patched on the surface of upper mold. Moving mold was held for enough time solidification was finished at the position where mold stopped, ingot was removed and used for inspection.

## 3. RESULTS

### 3.1 Water model experiment

Schematic diagram of observed flow pattern of three types of nozzle are shown in figure 4. In every case small eddy were observed in the vicinity of nozzle outlet. In this experiment, the length from nozzle outlet to point where eddy dispersed was defined the extent of turbulence and was called penetration length. The difference of flow pattern between single slit nozzle and separated slit nozzle was not clear. In both case, penetration length were small, so extent of turbulence were considered to small. In otherwise, penetration length of parallel pipe type nozzle was bigger than other two cases.



(a) (b) (c)

Fig. 4 Schematic diagram of observed flow pattern
(a)Single slit nozzle, (b)Separated slit nozzle,(c)parallel pipe nozzle

The reason of bigger penetration length of parallel pipe type is supposed to cause by smaller outlet area. Smaller outlet area causes bigger expansion of flowing area and faster flowing velocity at same flow rate. So, bigger eddy form and length which eddy is carried until it dispersed become longer. Penetration length of each cases were measured and relation between these length and flow rate are shown in figure 5. It is found that penetration length of parallel pipe nozzle is highly influenced by flow rate than slit type nozzles. In this experiment using water model, difference between tapered and flat face nozzles was not recognized.

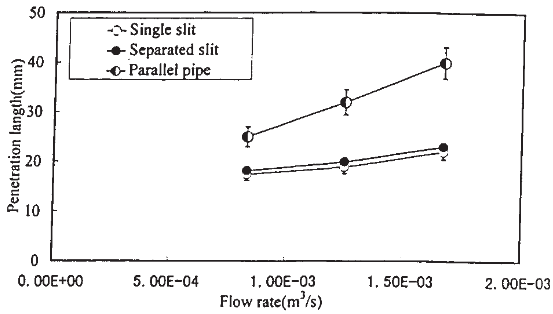


Fig. 5 Relation between penetration length and flow rate

### 3.1.2 Numerical simulation of fluid flow

Numerical simulation was carried out to investigate fluid flow by using slit type nozzle in detail. The purpose of simulation is to clarify the difference between single slit and separated slit type, and that of tapered and flat face nozzle. They were not able to recognize by water model experiment. Numerical calculation were conducted using 3-dimensional flow analysis code STREAM. Results of simulation are shown from figure 6 and 7. Figure 6 shows flow patterns using single slit nozzle and separated slit nozzle. In the case of using separated slit nozzle, low velocity zone are seen at front of wall which separate the nozzle. Figure 7 shows flow patterns in the vicinity of nozzle outlet of tapered face nozzle and flat face nozzle. This figure shows flow pattern observed from side of nozzle. There is not seen difference of penetration length clearly but the thickness of eddy of tapered face nozzle is smaller than that of flat face nozzle. It is considered that tapered face nozzle is effective to reduce the degree of turbulence. This difference could not recognized in the water model experiment because observation was made from front of nozzle. So, in the casting experiments tapered face nozzle were used in every cases.

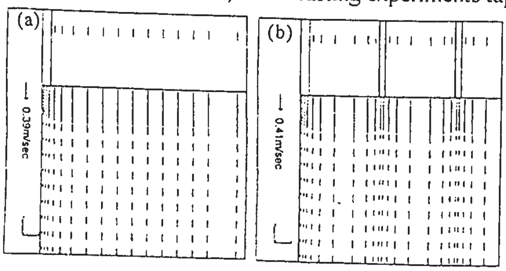


Fig. 6 Results of numerical simulation of flow pattern.
(a)Single slit nozzle,(b)Separated slit nozzle

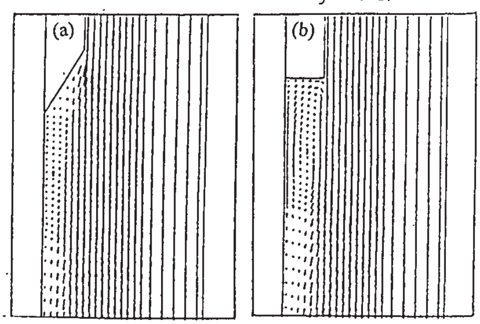


Fig. 7 Calculated flow pattern at the outlet of nozzle.
(a)Tapered tip nozzle,(b) Flat tip nozzle

## 3.2 Casting experiment

### 3.2.1 Surface quality

Surface appearance of ingot cast with moving mold and fixed mold are shown in figure 8. At the surface of ingot cast with fixed mold, a lot of flow lines are seen, and it indicates flow with eddy in the mold. Against case of fixed mold, there are almost no flow lines but some lines parallel to moving direction. It is clear that moving mold casting process has a effect of improving surface quality. Influence on roughness of ingot surface by the difference of nozzle shape are measured. Measurements were conducted at lower surface which cast by moving mold. Measured results are shown in figure 9. Results of single slit type and separated slit type are resembled but roughness of parallel pipe type is rather high. Two reason are considered, one is high extent of turbulence at the outlet of nozzle, which was observed in water model experiment. The other is existence of low molten metal supply regions between one pipe and another in parallel pipe nozzle. It tend to generate solidified shell on nozzle tip because of low heat supply rate at low molten metal supply regions. Stuck shell causes turbulence of fluid flow or surface defects by being involved to ingot. Appearance of surface defect caused by involving solidified shell to ingot is shown in figure 10. The thickness of oxide film on ingot surface were measured by auger electron spectroscopy. The results are listed in table 3, oxide film thickness of ingots cast by other casting process are also listed for comparison. Oxide film thickness of ingots cast by moving mold casting process are much thinner than other process. It is not clear that the difference among results of three nozzle type. The reason why oxide film thickness were so thin are considered as follows. One reason inlet of nozzle is exist near the bottom of tundish so it is able to avoid flowing oxide film at free surface into nozzle. And the other is adopting closed nozzle feeding method to reduce oxidation of fluid flow by atmosphere.

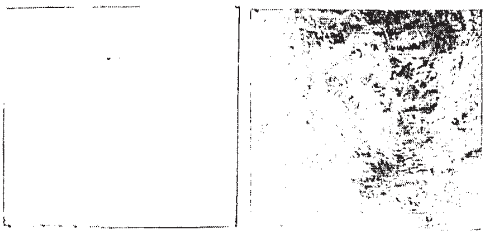


Fig. 8 Surface appearance of ingots.
(a)moving mold casting,(b)fixed mold casting

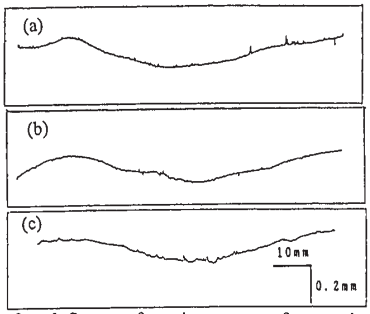



Fig. 9 Influence of nozzle type on surface roughness.
(a)single slit,(b)separated slit,(c)parallel pipe

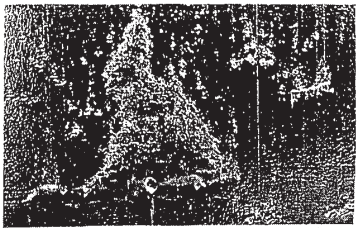


Fig. 10 Typical appearance of surface defects 10mm

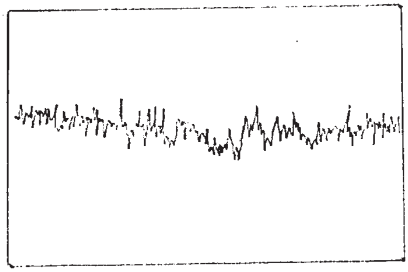
Table 3 Oxide film thickness on ingot surface

| Casting process(nozzle type) | Oxide film thickness(Å) |
|---|---|
| This work (single slit) | ,, |
| This work (separated slit) | ,, |
| This work (parallel pipe) | ,, |
| Direct chill casting | 500～1400 |
| Twin belt casting | 1400 |
| Twin roll casting | 1200 |

### 3.2.2 Internal quality

It was not observed the influences on internal quality by difference of nozzle type. The reason is considered that fluid flow are almost same after penetration length in which nozzle are used. Cooling condition also same, so solidification progress in same way. Internal quality of ingot cast by using separated slit nozzle are shown as example. A macro structure of ingot cross section and profile of Mg content are shown in figure 11and 12, respectively. It is seen slight negative segregation at the center of ingots.

Fig. 11 Macrostructure of cross section 20mm



2mm

Fig. 12 Mg concentration profile measured by XMA

## 4. CONCLUSION

In order to investigate the influence of molten metal flow on ingot characteristics the water model experiments, numerical analysis and casting experiments by using the simulator were carried out. The results are summarized as shown below.

(1) Moving mold casting process has a effect of improving surface quality.

(2) Extent of turbulence in case of parallel pipe nozzle was bigger than that of single slit nozzle and separated slit nozzle.

(3)Surface quality of ingots cast by using single slit nozzle and separated slit nozzle are resembled and better than that of parallel pipe nozzle.

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