# Development of Hybrid Melting Furnace for Aluminum Die Casting

K. KUMANO　Y. MATSUURA　H. URUSHIDANI

*We have developed a hybrid melting furnace for the purpose of raising fuel efficiency and reducing $CO_2$ within the melting process of aluminum die casting. Conventional melting furnaces used a gas burner to supply the necessary heat for the melting, temperature raising and holding processes, however the newly developed hybrid melting furnace uses a gas burner for the melting process which requires heating over a short period of time, and an electric heater, which is heat-efficient, for all other processes. In addition, the new furnace cuts heat radiation by downsizing the furnace body, achieving a much higher fuel efficiency and reduced $CO_2$. This has resulted in a 50% decrease in $CO_2$ emissions and 71% decrease lowering molten metal consumption rate.*

***Key Words****: Aluminum die casting, melting furnace, hybrid, electric heater, $CO_2$*

## 1. Introduction

Aluminum die casting is a type of metal casting whereby molten aluminum alloy is injected into a mold and turned into a casting with high dimensional accuracy in a short period of time. Generally, melting furnaces are used to melt aluminum alloy.

In the automotive industry, initiatives to reduce $CO_2$ emissions are accelerating as part of addressing global warming and this need has been growing stronger every year, even in relation to the aluminum die casting process. As such, this report introduces the development of a hybrid melting furnace (the developed furnace) and the effects this has had on reducing the volume of $CO_2$ emissions generated in the melting process of aluminum die casting.

## 2. Development Aims

In order to reduce the volume of $CO_2$ emissions generated by a melting furnace, there is a need to reduce the energy consumption of the respective processes; melting, temperature raising and holding, or in other words, improve the fuel efficiency of the melting furnace. As such, first, JTEKT devised its own method to measure the amount of heat radiated by a melting furnace, which had been left up to the equipment manufacturer until now. Next, using this method, we compared efficiency and $CO_2$ emissions for each type of energy and determined the optimal energy to use for each melting process based on the amount of heat needed.

In conventional melting furnaces (conventional furnaces), a gas burner was used as the sole heat source for heat required by the melting, temperature raising and holding processes. Melting in a melting furnace involves loading an aluminum alloy ingot (aluminum alloy) into the melting chamber and melting this using a gas burner at around 580℃. Afterwards, the ingot is placed in the temperature-raising chamber where it is heated to a set temperature ranging from 680℃ to 700℃ or more using a gas burner then supplied to a die cast machine as molten metal from the pumping port of the holding chamber via a molten metal supply unit (**Fig. 1**).

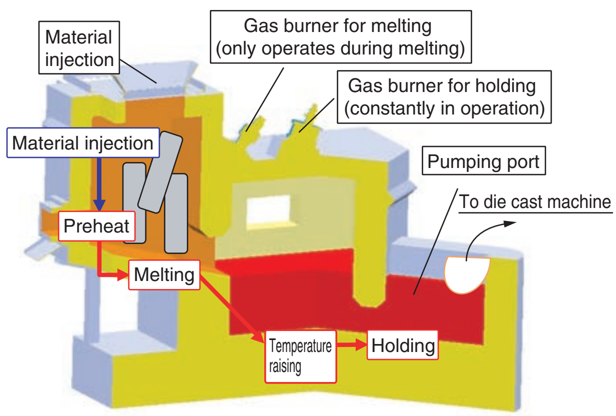



**Fig. 1** Process of melting furnace

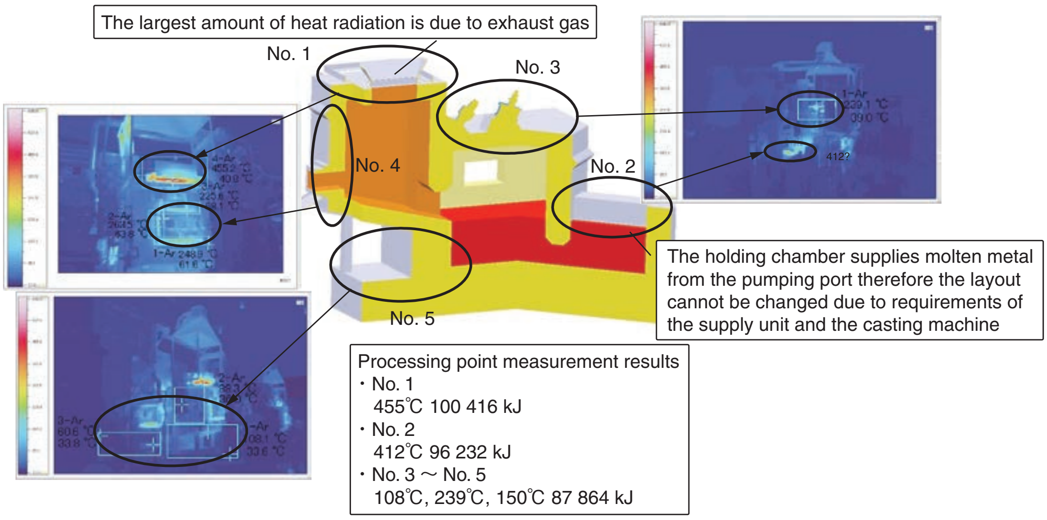



**Fig. 2** Results of measurement of heat radiation from conventional furnace

The feature of this conventional furnace layout was that the heat of the gas burner as the heat source, directly heated material and molten metal and, as such, part of the heat radiated reflected on the ceiling or walls of the furnace, becoming reflective heat and heating the molten metal further. In other words, this is a typical reverberatory furnace. From the perspective of fuel efficiency, reverberatory furnaces raise two issues, heat radiation due to discharged gas and heat radiation of the furnace itself.

It would be desirable to trap the exhaust gas emitted by the gas burner in the furnace and increase heat efficiency, however, if the holding chamber is sealed, the exhaust gas will eventually pressurize the molten metal and it will start to overflow from the pumping port. Therefore, there is a need for a ventilation port to allow the exhaust gas to be dispelled from the furnace and prevent it from pressurizing the holding chamber and, due to this, the increase in exhaust gas-derived heat radiation in face causes fuel efficiency to decrease.

In order to increase efficiency as a reverberatory furnace, it is possible to transmit the reflective heat efficiently to the molten aluminum metal by shaping the furnace body like a boat (wide and shallow), for example. However, if the furnace body was made a wide, shallow shape would increase in overall size, which would in turn increase heat radiation from the furnace itself and cause fuel efficiency to decrease.

Here, we used a processing point measurement method to take actual measurements of the exhaust gas-derived heat radiation and furnace body-derived heat radiation in a conventional furnace (**Fig. 2**) and made a comparative verification of the theoretical values and the actual values obtained through such a measurement (**Table 1** and **2**). As a result, we ascertained from **Fig. 3** and **Fig. 4** that

**Table 1** Amount of heat radiation from conventional furnace

| Heat radiation portion | Heat radiation amount, kJ |
|---|---|
| Upwards heat radiation | 18 828 |
| Vertical heat radiation | 47 279 |
| Downwards heat radiation | 14 644 |
| Heat radiation from molten metal surface | 39 116 |
| Overall heat radiation (total) | 119 867 |

**Table 2** Comparative results

| | Heat radiation amount, kJ | |
|---|---|---|
| | Theoretical value | Actual value |
| Furnace body-derived heat radiation | 119 867 | 87 864 |

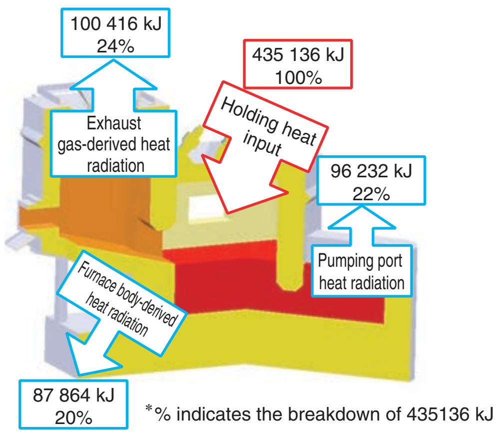



**Fig. 3** Schematic diagram of melting furnace heat radiation

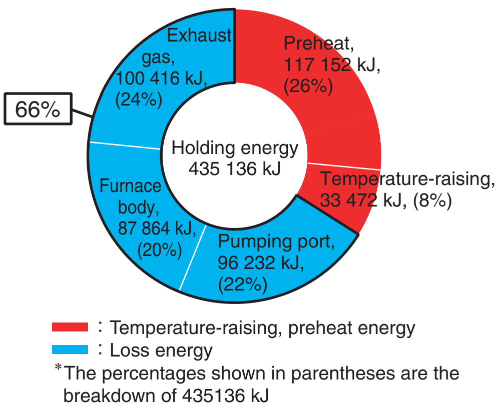
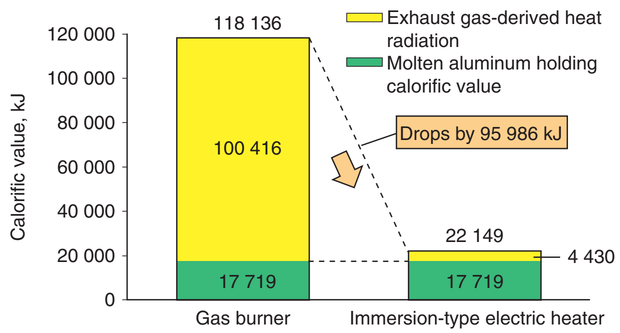



**Fig. 4** Breakdown of energy efficiency




[Conditions]
- Gas burner efficiency: 15%
- Immersion-type electric heater efficiency: 80%
- Exhaust gas-type heat radiation (from **Fig. 4**): 100 416 kJ
- Calorific value necessary for holding molten aluminum: (100 416 ÷ 85%) × 15% = 17 719 kJ
- Exhaust gas-derived heat radiation from an immersion-type electric heater: (17 719 ÷ 80%) – 17 719 = 4 430 kJ

**Fig. 5** Comparison of exhaust gas heat radiation with different heat source

the energy loss of exhaust gas-derived and furnace body-derived heat radiation accounted for approximately 66% of the overall loss. Moreover, energy efficiency of the gas burner is poor, averaging at around 15% (**Fig. 5**). Therefore, when developing our hybrid melting furnace, our aim was to reduce both of the above-mentioned forms of heat radiation in order to improve fuel efficiency and reduce $CO_2$ emissions.

Furthermore, we made a comparison of the melting methods in the melting chamber and decided to melt the aluminum alloy using a gas burner for the developed furnace, in the same way as the conventional furnace (**Table 3**).

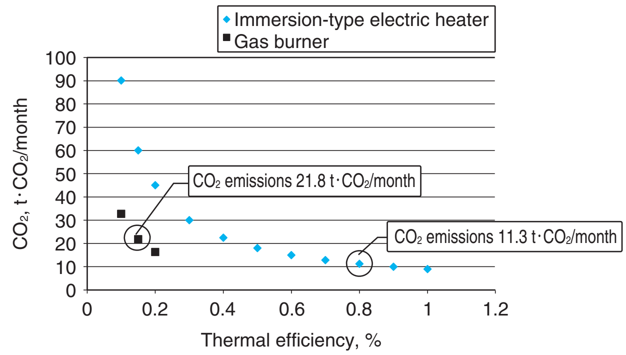



**Fig. 6** Efficiency and $CO_2$ emissions of gas burner/immersion-type electric heater

## 3. Specifications and Design of the Developed Furnace

### 3. 1 Reduction of exhaust gas-derived heat radiation

One way to reduce exhaust gas-derived heat radiation would be to change the gas burner, which has poor efficiency, into a new heat source, and significantly decrease the amount of exhaust gas. In light of this, we examined using an immersion-type electric heater as a new heat source for the temperature-raising and holding processes on the developed furnace. As seen in **Fig. 5**, by changing the heat source to an immersion-type electric heater, it was possible to reduce heat by 95 986 kJ – the difference between the exhaust gas-derived heat radiation of the gas burner (100 416 kJ) and the exhaust gas-derived heat radiation of the immersion-type electric heater (4 430 kJ). In terms of $CO_2$ emissions, as **Fig. 6** shows, with the 80% efficiency of the immersion-type electric heater, a reduction of 10.5 (21.8 - 11.3) t·$CO_2$/month is possible. Moreover, by changing the heat source to an immersion-type electric heater, the furnace body size is made compact thus fuel efficiency can be improved.

**Table 3** Comparison of melting methods

| | Gas burner | | Electric heater | | Electromagnetic induction heating (IH) | |
|---|---|---|---|---|---|---|
| Heating method | Direct heating | Evaluation | Indirect heating | Evaluation | Direct heating | Evaluation |
| Efficiency | Direct heating with good efficiency | ○ | Indirect heating with poor efficiency (air has poor heat transfer) | △ | ・Aluminum alloy has low permeability, and depth of penetration becomes deeper<br>・If frequency is high, the depth is shallow and efficiency is poor | × |

Consequently, we decided to use an immersion-type electric heater as the heat source for the temperature raising and holding processes.

### 3. 2 Reduction of furnace body-derived heat radiation

Two options for reducing furnace body-derived heat radiation are (1) making the furnace body size compact and (2) improving thermal insulation performance.

Moreover, the determining factor of furnace size is not the aluminum alloy melting capacity, but rather the heat source.

Here, as discussed in **Section 3. 1**, it is possible to make the furnace body size compact by changing the heat source of the temperature-raising chamber and holding chamber to an immersion-type electric heater, thus improving fuel efficiency. Here, specifications were revised to reduce the gas burner combustion space and use highly-insulating, thin thermal insulation material for the furnace, the molten metal height was determined from the heat generation length of the immersion-type electric heater, and we decided upon a molten metal holding capacity of 700 kg and furnace size of 2 950mm ×2 271mm ×1 800mm. In order to verify this result, we calculated heat radiation and obtained the amount of furnace body-derived heat radiation (**Table 4**).

**Table 4** Amount of heat radiation from developed furnace

| Heat radiation portion | Heat radiation amount, kJ |
|---|---|
| Upwards heat radiation | 11 966 |
| Vertical heat radiation | 18 728 |
| Downwards heat radiation | 6 673 |
| Heat radiation from molten metal surface | 39 116 |
| Overall heat radiation (total) | 76 484 |

The result of these changes, as **Table 1** and **4** show, was a reduction in furnace body-derived heat radiation of 43 383 (119 867 - 76 484) kJ. Furthermore, considering that the melting mechanism is the same with a molten metal holding capacity of 700 kg, the melting chamber supplies aluminum alloy melted at approximately 580℃ to the temperature-raising chamber. The temperature-raising chamber ranges from 680 to 700℃, and there is no heat source in the holding chamber. Therefore, when molten metal is supplied from the temperature-raising chamber to the holding chamber, the temperature of the molten metal drops. With consideration to this point, we installed immersion-type electric heaters in both the temperature-raising chamber and the holding chamber to secure a heat source in the holding chamber also, thus preventing the temperature of the molten metal from dropping.

In terms of improving the thermal insulation performance, the insulation coating (heat-resistant silver) of a general melting furnace has a heat resistant temperature of 250℃ or less, and peels away if used in conditions which exceed this temperature. Moreover, the furnace temperature is higher, the more portions there are which radiate heat and these portions exceed the heat resistant temperature, therefore this insulation coating is not suitable for the melting furnaces used in aluminum die casting. In light of this, we decided to adopt thermo resin as an insulation coating with a heat resistant temperature of 600℃ for the developed furnace (**Fig. 7**). In relation to the results of a furnace heat radiation measurement shown in **Table 4**, we calculated the furnace heat radiation when thermo resin was used on the furnace's exterior wall (**Table 5**).

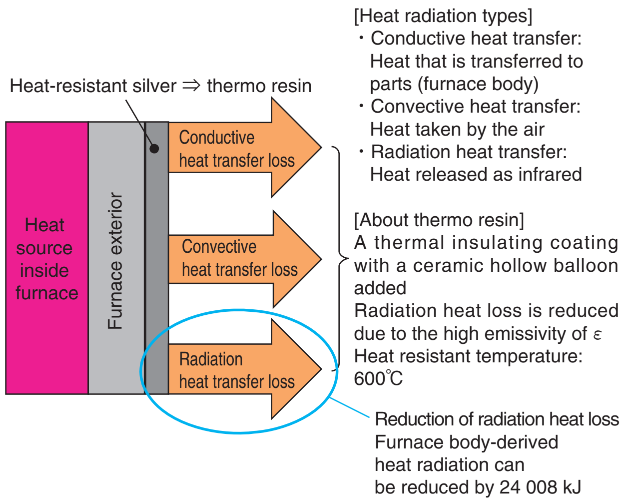



**Fig. 7** Heat-insulated coating

**Table 5** Results of calculation of heat radiation from developed furnace/heat-insulated coating during operation

| Heat radiation portion | Heat radiation amount, kJ |
|---|---|
| Upwards heat radiation | 4 473 |
| Vertical heat radiation | 7 196 |
| Downwards heat radiation | 1 515 |
| Heat radiation from molten metal surface | 39 292 |
| Overall heat radiation (total) | 52 476 |

The result of this change, as **Table 4** and **5** show, was a reduction in furnace body-derived heat radiation of 24 008 (76 484 - 52 476) kJ. As **Table 4** and **Fig. 5** shows, the necessary calorific value of the immersion-type electric heater is 118 359 [(76 484 + 22 149) multiplied by a safety ratio of 1.2] kJ or higher. As such, in order to satisfy this requirement, three units of 21 600 kJ were set up in the temperature-raising chamber and three units of 21 600 kJ were set up in the holding chamber, therefore achieving a total of 129 600 kJ for all six.

As described in **Section 3. 1** and **3. 2**, we were able to finalize the layout and specifications of the developed furnace. For the developed furnace, a gas burner is used as a heat source for the melting chamber, while immersion-type electric heaters are used as heat sources for the temperature-raising chamber and holding chamber, consequently leading to the development of a hybrid (gas and electric) melting furnace. **Figure 8** shows the structure of the developed furnace while **Table 6** shows a comparison of specifications for the conventional furnace and developed furnace.

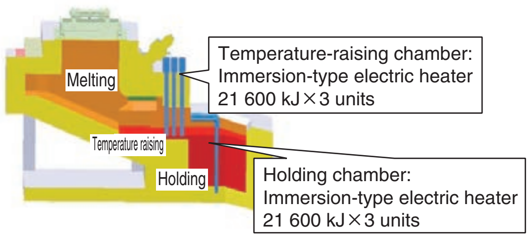



**Fig. 8** Structure of developed furnace

**Table 6** Comparison of specifications of conventional furnace and developed furnace

| | Conventional furnace | Developed furnace |
|---|---|---|
| Melting capability | 200 kg/h | 200 kg/h |
| Melting chamber | Gas burner 836 800 kJ | Gas burner 836 800 kJ |
| Molten metal holding capacity | 1 000 kg | 700 kg |
| Furnace body size | 3 870mm× 2 595mm× 3 311mm | 2 950mm (▲23.8%)× 2 271mm (▲12.5%)× 1 800mm (▲45.6%) |
| Holding capability | 700℃ ±10℃ | 700℃ ±3℃ |
| Temperature-raising chamber | Gas burner 502 080 kJ | Immersion-type electric heater 64 800 kJ |
| Holding chamber | — | Immersion-type electric heater 64 800 kJ |

## 4. Results on an Actual Furnace

The developed furnace designed as described in **Section 3** was introduced to a production line and its results verified for a duration of one year from May 2016 through April 2017.

### 4. 1 Effect on reducing $CO_2$ emissions

The developed furnace was able to reduce $CO_2$ emissions by 50% compared to a conventional furnace. **Figure 9** shows the $CO_2$ reduction effects.

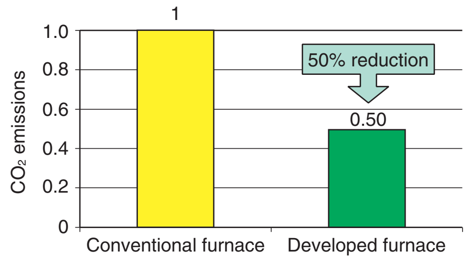



**Fig. 9** Results of reduction of $CO_2$ emissions

### 4. 2 Effect on reducing the molten metal consumption rate

The molten metal consumption rate of the developed furnace was reduced by 71% compared to that of a conventional furnace. **Figure 10** shows the effect on reducing the molten metal consumption rate.

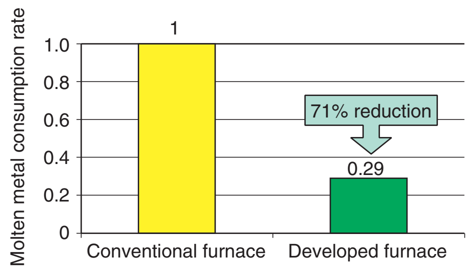



**Fig. 10** Results of lowering molten metal consumption rate

## 5. Conclusion

As a result of this development, we succeeded in reducing exhaust gas-derived heat radiation by adopting immersion-type electric heaters and reducing furnace body-derived heat radiation by making the furnace body size compact and using insulation coating, thus reducing $CO_2$ emissions by 50% and the molten metal consumption rate by 71%.

In order to design, fabricate and verify the results of the developed furnace, there were many points that could not be predicted with prior examination based on theoretical calculations. However, by utilizing the processing point measurement technique devised independently by JTEKT, it was possible to make a quantitative judgment and efficiently determined the optimal furnace body layout and specifications.

The developed technologies described in this paper of the immersion-type electric heater and insulation coating (thermo resin) can be horizontally-deployed to existing conventional-type furnaces, and all of the technologies can be deployed to updated furnaces. Moving forward, we would like to leverage this technology to help in solving environmental issues which will continue to receive more and more attention.



K. KUMANO* Y. MATSUURA* H. URUSHIDANI*

* *Casting & Forging Production Engineering Dept., Production Engineering Headquarters*