Technology Introduction

Development of Die Casting Analysis Techniques

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1 Introduction

The gear case for KYB'S electric power steering (hereinafter referred to as "EPS") for vehicles and the component called "body" for the vane pump for hydraulic power steering (hereinafter referred to as "HPS") are manufactured using the die casting method (Fig. 1).

EPS uses the torque, which is generated by the electric motor in the vehicle steering operation, as power assistance. The vane pump for HPS is necessary in safe driving by enabling steering operations with few operations and quickly responding to avoid danger, etc. by using hydraulic power.

Casting faults, such as shrinkage cavities, in these die casted components can lead to rust from water seeping and working fluid leakage, causing operation failure.

If casting faults occur in the prototype stage, we must respond to the fault through additional prototypes. Therefore, the mold modifications and prototypes require budget and time.

In this report, I would like to introduce our efforts to improve the fault prevention accuracy level of die casting simulation with the aim of reducing the development lead time as well as their application examples.

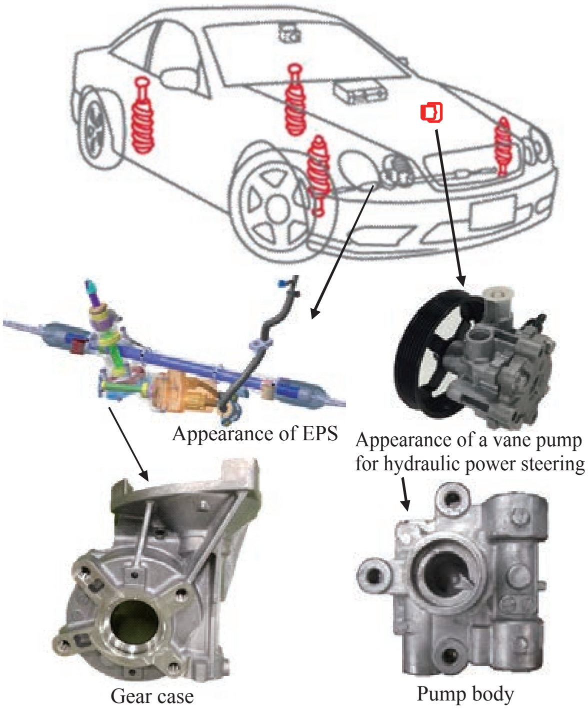

Fig. 1 Example of KYB's die-casting components

2 Casting Faults and Measures

Casting faults include gas entrainment, flow lines, and shrinkage cavities (Fig. 2).

In gas entrainment, air that is entrained when molten metal is injected into the mold is left inside the product as bubbles. The countermeasure against gas entrainment is to create passages for the molten metal that are less prone to entraining air.

Flow lines are surface faults, in which molten metal solidifies before completely fusing, creating wrinkle-shaped cavities. The countermeasure for these faults is to prevent the molten metal temperature from dropping.

Shrinkage cavities refer to gaps created within the product due to solidification shrinkage of the molten metal. They are mainly seen at the center of thick parts or parts that solidify last. Countermeasures for shrinkage cavities include directional solidification by enhancing

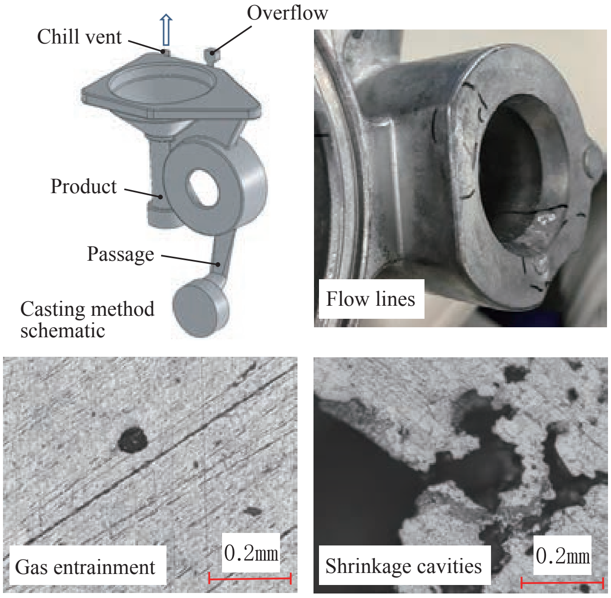

Fig. 2 Casting method and casting faults

the cooling of thick parts, supplementing molten metal through local pressure.

These faults deteriorate products' mechanical properties. If faults surface after machining, they can cause leakage. However, shrinkage cavities and gas entrainment in products cannot be avoided in die casting due to the production process. Therefore, we prevent outflow of faulty units through visual inspections and leak tests. In addition, in case of high defect rates, we had been changing the mold or injection conditions based on past experiences to address the issues. However, these measures had issues, such as prolonged lead time in mold modification and multiple modifications.

3 Improving the Simulation Prevention Accuracy Level

For the simulation software, we used the commercial analysis software for casting (ADSTEFAN [Note 1]). In order to utilize the simulation, the existence and locations of the faults must match between the actual product and the simulation. With the actual casting faults, we used an X-ray CT scan to confirm the gap distribution and observed the cross-section of each part, thus categorizing them into 2 fault types of "shrinkage cavities" and "gas entrainment". The simulation software comes with physical property values, such as specific heat and thermal conductivity, as default. However, directly using these values does not enable us to accurately predict fault occurrence. Therefore, we decided to improve the prediction accuracy with the following procedure.

Note 1) Registered Trademark of Hitachi Industry & Control Solutions, Ltd.

3.1 Improving the Temperature Distribution Prediction Accuracy

Reproducing the actual product's mold temperature through simulation is necessary in order to predict faults in fluidity and solidification analysis. In order to do so, the temperature distribution prediction accuracy of the simulation must be improved.

Casting models consist of elements, such as molten metal, mold, and water-cooling tubes for the mold (Fig. 3). In order to improve the temperature distribution prediction accuracy, we must comprehend the physical property values unique to each element, such as specific heat and density, as well as heat transfer coefficients between elements. With physical property values unique to each element, we measured the specific heat, density, thermal conductivity, and viscosity and reflected the actual measurement values on the simulation.

Since we were unable to measure the heat transfer coefficients, we measured the mold temperature with thermography and made adjustments so that the measured temperature could be reproduced in the simulation.

With the default physical property values, there was as much as +100˚C and over temperature differences. By adjusting the heat transfer coefficients with the actual measured physical property values, we were able to maintain the temperature difference with the actual product under 20˚C maximum (Fig. 4). In addition, we were also able to maintain the temperature difference with the actual products of different models under 20˚C maximum without re-adjusting the physical property values, as long as the materials and process were the same.

3.2 Improvement of Fault Prediction Accuracy

We evaluated the gas entrainment with the "maximum air pressure", which displays the gas pressure from the start of injection to completion. Based on the idea that gas entrainment occurs when the pressure of the entrained air

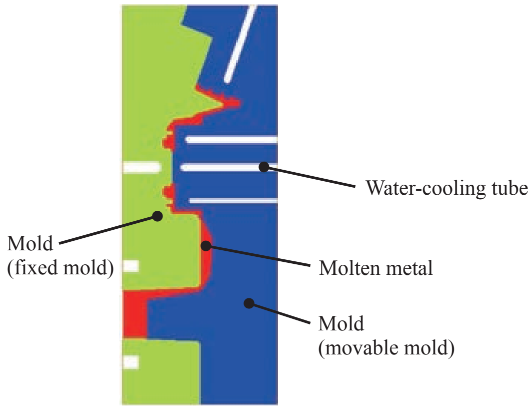

Fig. 3 Schematic of a casting model

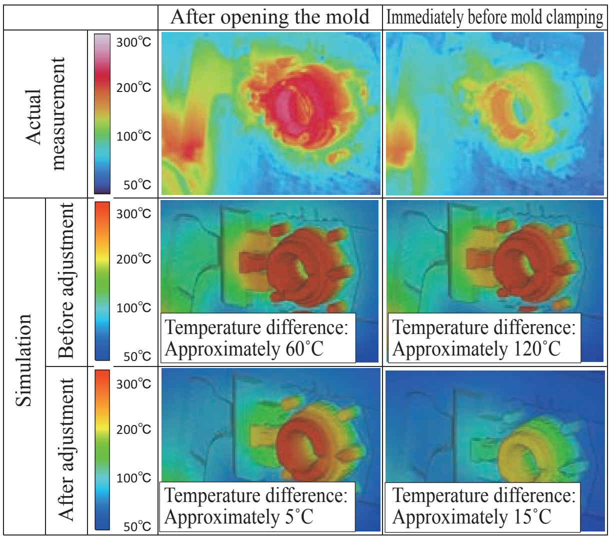

Fig. 4 Calibration result of mold temperature distribution

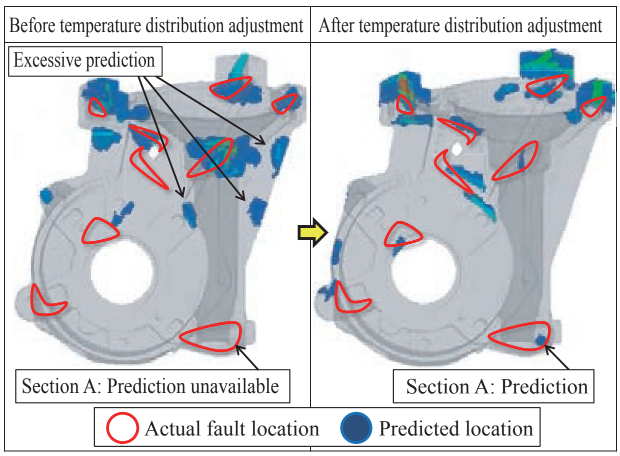

Fig. 5 Gas entrainment prediction result

becomes high, we only displayed areas with a certain gas pressure or above. As a result, we were unable to predict Section A in the default condition, and faults were excessively predicted in other areas. By shifting the physical property values and temperature distribution closer to the actual values, we were able to predict Section A and reduce the excessive prediction areas. Due to this, we were able to improve the gas entrainment prediction accuracy (Fig. 5).

The locations of the flow lines in an actual product matched the locations of the flow lines where the "air contact time" of the molten metal is long and the temperature is low where the molten metal meets when the filling process is completed (Fig. 6).

For the prediction method of shrinkage cavities, we used the "soundness of degree" which considers the solidification shrinkage of molten metal and the shift of the molten metal caused by solidification shrinkage. Soundness is represented in terms of ratio, and the smaller the value is, the greater the shrinkage cavity risk is. As with gas entrainment, we were able to improve the prediction accuracy by shifting the physical property values and temperature distribution closer to the actual values (Fig. 7). In addition, we were also able to match the locations of shrinkage cavities with the "solid phase rate", in which unsolidified areas within solidified product were identified (Fig. 8). We learned that soundness can also reproduce the local pressure Note 2) effect and that unsolidified areas can predict the shrinkage cavity range with good accuracy.

Note 2) Method to supplement the molten metal that shrinks from solidification by directly applying pressure to part of the mold during the solidification process.

4 Simulation Application Examples

4.1 Measure for Gear Case Shrinkage Cavities

We studied the gear case in which a fault in Section A was found in order to determine the cause and to take countermeasure for the fault (Fig. 9). The observation result showed that Section A mainly had shrinkage cavities. Therefore, we considered the measure through simulation prior to conducting the casting experiment.

We responded to shrinkage cavities by enhancing the mold cooling process. We added water-cooling tubes where additional cooling is possible from the structural perspective of the mold. The simulation demonstrated that the mold temperature reduced and the unsolidified part

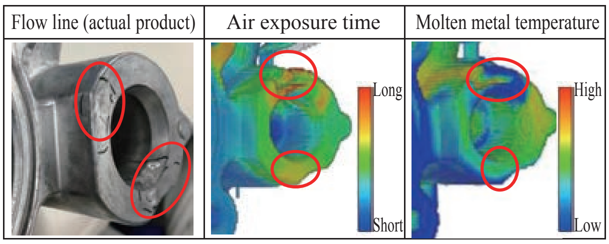

Fig. 6 Flow line prediction result

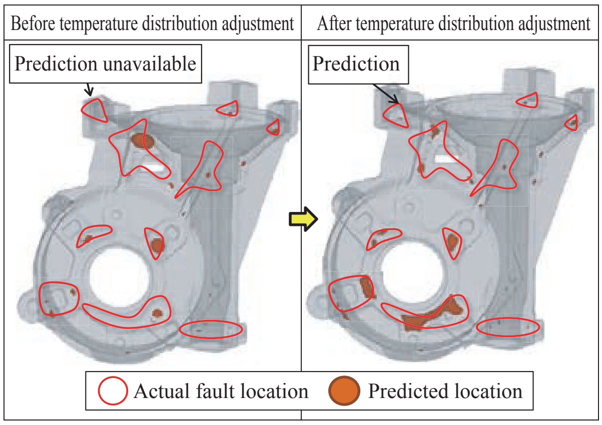

Fig. 7 Shrinkage cavity prediction result (Soundness)

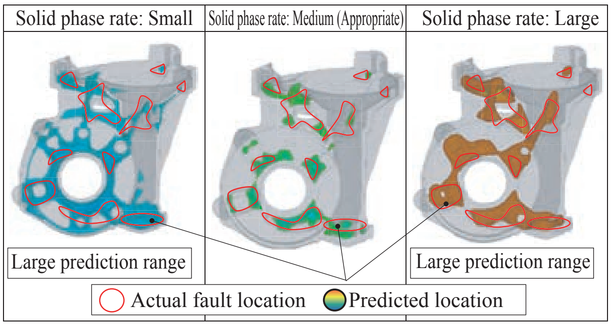

Fig. 8 Shrinkage cavity prediction result (Unsolidified area)

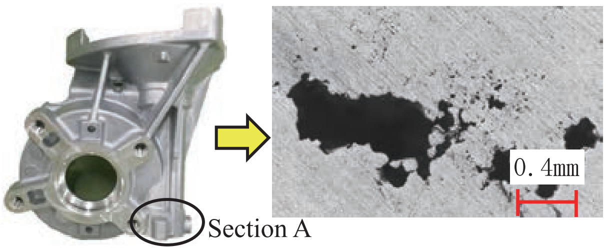

Fig. 9 Fault in Section A of a gear case

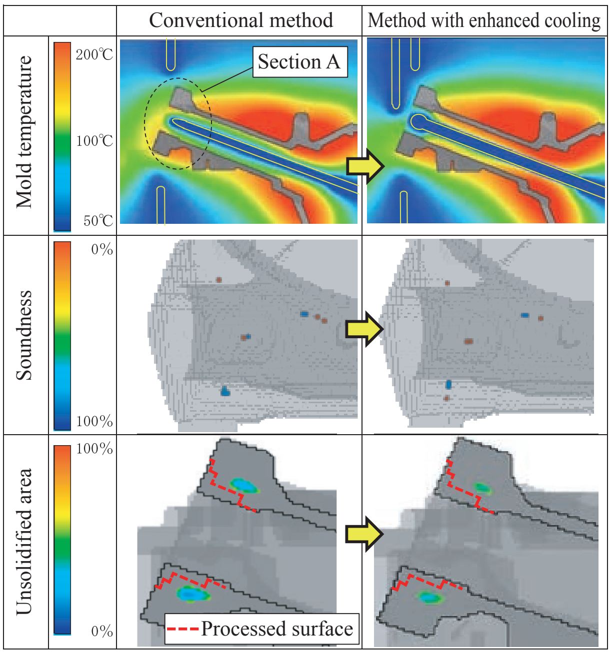

Fig. 10 Difference in shrinkage cavity distribution due to enhanced cooling

was made smaller with the same soundness (Fig. 10). Based on this result, we determined that the risk of the shrinkage cavities being exposed on the processed surface after the machining process and leading to leakage would be reduced, although the shrinkage cavities cannot be completely removed.

As a result of the casting experiment, we were able to reduce the extent of shrinkage cavities and significantly reduce the leakage defect rate.

4.2 Flow Line Measure

Flow lines were seen in a similar-shaped component in the past when considering the casting method for a new model. It was highly likely that flow lines would occur in the same place, so we took measures when considering the casting method through simulation.

The simulation result presented that the locations of the flow lines were where the molten metal met from both sides of the mold hole and that the molten metal temperature was lower where it met.

As a countermeasure, we created an overflow in the gap where the molten metal meets so that the overflow is the last section to be filled, thus guiding the reduced-temperature molten metal into the overflow.

As a result, no flow line occurred in the section from casting, allowing us to launch the mold without modification. This led to the reduction of development lead time (Fig. 11).

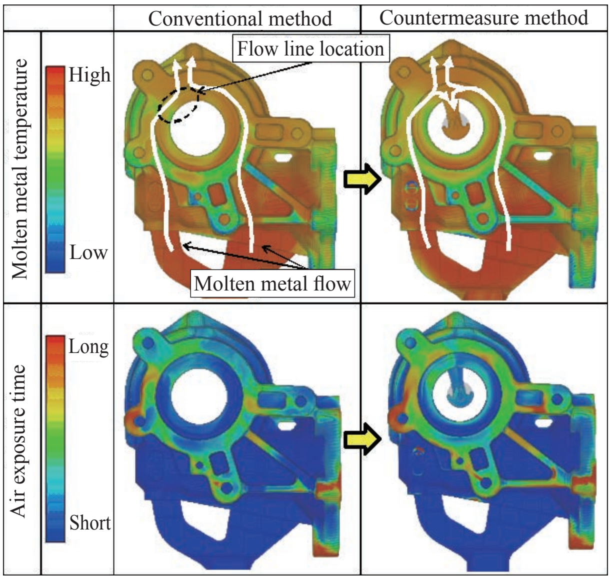

Fig. 11 Flow line measure through overflow addition

5 In Closing

It took a long time for the simulation results to reproduce actual faults, but they reached the usable level in this development. However, there are still aspects that cannot be fully predicted, and we must further improve the simulation accuracy. Due to this, we consider that it is important to accumulate internal know-how by increasing the number of case studies.

We will continue utilizing the developed fault prediction methods and make efforts to reduce the development lead time and improve productivity through theoretical considerations of casting methods. Finally, I would like to express my sincere gratitude for relevant parties and everyone who provided guidance and support.

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