Application of Computer Simulation in Developing Automotive Parts of Al alloy by Using Semi-solid Die Cast Process

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Abstract To aid the optimizing design of filling system, computer simulation technique is introduced to predict injection-forming process and to protect defects during trial manufacture of automotive parts by using semi-solid die cast process. By comparing formed appearance of parts in experiments and that in simulations, and observing the relationship between internal defects inspected by X-ray and flow field obtained in simulation, it is indicated that there are quite good agreements between simulation and experiment, right predictions for cast defects resulting from filling process can be made and improving direction is proposed. The realization of numerical visualization for filling process of high speed during semi-solid die cast process will play an important role in optimizing technology plan and process.

Introduction

Semi-solid die cast process with many features \cite{1}, \cite{2} is a forming technology developed on the base of general molten metal die cast, and is gradually becoming maturity as near-net-shape processing of material. Comparing with traditional die cast, there are a lot of unsolved technology problems in Semi-solid die cast process. For example, because mature data are absent from the design of gating system, design experiences in die cast of molten metal are used. To optimize forming process, to aid the die design and to forecast cast defects, the introduction of computer simulation will play an important promoting role in enhancing technique level of semi-solid formation and product quality. As one of the steps in which automotive parts are systematically developed, using simulation technique during trial manufacture of Al alloy parts aims at optimizing forming technology and improving quality of product.

Method

An induction device of medium frequency with circled multi-position heats billets of Al alloy (A356) to semi-solid state, and then forms a part by using die cast machine of 500 tons in our laboratory. The pushing pole of this machine is connected with displacing sensor, and when the moving state of pushing pole during filling is auto-recorded by control computer, these results are simultaneously reflected in monitor. Four dies (as shown in Fig.1) are used in this study, and the developments of actual automotive parts are carried out on the basis of previous works \cite{3}. Casting simulation tool ADSTEFAN \cite{4} is used for computer simulation of filling process.

Fig.1 3-D model of samples and parts
Results and discussion

Initial investigation of plate sample. The displacing curves of filling process have been measured in two filling pattern (slow and rapid), and representative results of two groups are shown in Fig.2. Due to the difference of recorded starting point, there existed different positions in filling displacing curves of same group, but their shapes were close resemblance. Therefore, quite stable filling processes were revealed. Effective push speeds of filling head were minutely estimate to be respectively 0.8 m/s (rapid type) and 0.3 m/s (slow type).

![Displacing curves of filling head](image)

(1) Slow type (2) Rapid type

Fig.2 Displacing curves of filling head

Using the above speed carried out computer simulations, and main physical properties and calculation condition are shown in Table 1-2. Reference [5] and standard database supplied by cast simulation software were referred in the selection of physical properties. Kinematic viscosity was so expressed with subsection function related to solid fraction that semi-solid state was well reflected. The comparison for confirmation between try-calculations and experiments were enforced, according to a simulation result and experimental result of short-shot (as shown in Fig.3), both filling pattern and un-filling area were similar. So, it is reliable to reappear filling process with the help of this simulation, that is to say, realization of visibility in numerical value.

Table 1 Physical properties of Aluminum alloy A356

<table>
<thead>
<tr>
<th>Density kg/m³</th>
<th>Specific heat kJ/(kg K)</th>
<th>Thermal conductivity W/(m K)</th>
<th>Latent heat kJ/kg</th>
<th>Kinematic viscosity m²/s</th>
<th>Liquids K</th>
<th>Solidus K</th>
</tr>
</thead>
<tbody>
<tr>
<td>2700</td>
<td>0.96</td>
<td>155</td>
<td>389</td>
<td>Function of solid fraction</td>
<td>887</td>
<td>850</td>
</tr>
</tbody>
</table>

Table 2 the relationship for Aluminum alloy A356 between kinematic viscosity and solid fraction

<table>
<thead>
<tr>
<th>solid fraction, %</th>
<th>0</th>
<th>0-60</th>
<th>&gt;60</th>
</tr>
</thead>
<tbody>
<tr>
<td>kinematic viscosity</td>
<td>$1 \times 10^{-5}$</td>
<td>Linear inserting value</td>
<td>$1 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

Table 3 Calculation condition

<table>
<thead>
<tr>
<th>Billet temperature K</th>
<th>Pushing speed of filling head m/s</th>
<th>Die preheated temperature K</th>
</tr>
</thead>
<tbody>
<tr>
<td>863</td>
<td>0.3 and 0.8</td>
<td>523</td>
</tr>
</tbody>
</table>

![Comparison of filling process in slow type between simulation and experiment](image)
**Forward control arm.** Carrying out short-shot try in the condition of low type captured a stopover state shown in Fig.4 (2), and the results of computer simulation (Fig.4 (1)) and X-ray inspection (Fig.4 (3)) at the same condition was compared in Fig.4.

![Simulation](image1)

![Experiment](image2)

![X-ray inspection](image3)

Fig.4 Comparison of filling state in slow type among simulation, experiment and X-ray inspection

The position indicated in simulation figure by an ellipse symbol is un-filling area, and is predicted to easily produce cast defects. Die-casting (shown in Fig.4 (2)) acquired by experiment existed somewhat hollow in the above near position; the inner defect that appeared in light white area marked an ellipse in X-ray inspection gave general agreement with that of simulation and appearance observation. Moreover filling state of die-casting was similar to that in simulation; for example, filling in the left side was a little quicker than that in the right side. Compared analysis was also carried out in rapid type and its result showed in Fig.5.

![Defect pattern in X-ray inspection](image4)

![Simulated cross-section](image5)

Fig.5 Comparison of filling state in rapid type between simulation and X-ray inspection
Foul-up spoor as shown in Fig.5 (1) was a residual trace after short shot and showed the state of a midway turbulence during filling. This is a visualization method for indirectly observing filling process. According to the simulating result shown in Fig.5 (2), later filled portion than surroundings expressed turbulence state was easy to bring on immixture of gas and bad filling; simulated turbulence area was a little inclined to left side and quite similar to that found in X-ray inspection. The good accordance between simulation and experiment was further proved to enhance the belief that simulation is able to act as a useful tool to aid plan design and defect countermeasure.

**Rear bridge support.** As a point part (as shown in Fig.1 (3) and (4), remodeled one time) of this study, developed samples must be tested in desk frame experiment and passed 450 thousand cycles requested by customer. Because this part has quite complicated shape and is easy to result in some cast defects concerned with filling process, plan design need to be optimized to develop satisfied product. In desk frame experiment, a part once cracked in the front of gate of die-casting as shown in Fig.6.

![Crack position in desk frame experiment](image)

This rear bridge support cracked after desk frame experiment of 443 thousand cycles, and its crack position just got across the entrance of gate. Because cold shut of about 1mm depth in 7mm cross-section and crack extension area was observed, crack source was considered to be this position by lapsing analysis. To estimate possibly conducted reasons, filling process that was minutely analyzed by computer simulation is shown in Fig.7.

![Simulating results of filling process for supporting part of Rear Bridge](image)

According to the simulating results, the front of gate was sequentially un-filled during filling. Air was easy to be involved and/or cold shut may be brought about in un-filling area. This position was entirely consistent with that of fatigue fracture in the above desk frame experiment. Therefore, improving filling state near the gate was considered to be quite important for enhancing fatigue property of die-casting. This essential information was applied to remodeling product (as shown in...
Fig.1 (4)) for plan design. Because new and old products were generally similar, some technology plans in redesigning gating system were supposed on the base of the past plan and investigated by computer simulation. Optimized plan (the thickness of gate was added from 6mm to 10mm, and the shape of gate was improved, but other technology parameters was fixed.) from a lot of supposed ones was chosen. The results of flow simulation and X-ray inspection were shown in Fig.8.

![Simulation and X-ray inspection results for optimized plan](image)

It can be seen that applying this optimized plan is able to rapidly fill the front of gate and perfect filling state is be acquired. No defects in the front of gate are found by X-ray inspection. We have enough reason to believe that suitably using computer simulation can shorten the developing period of semisolid die and improve the quality of products.

**Summary**

The defects, concerned with filling, forecasted by computer simulation are quite similar to tested ones in actual parts. Simulation can dynamically show flow tracks in die cavity and numerically realize the visibility of filling process. It is indicated that computer simulation is an effective method for optimization of filling plans and reduction of periods in the development of new parts.

**References**


