International Journal of the Korean Society of Precision Engineering Vol. 4, No. 2, March 2003.

A Study on the Design of Gating System for Semi-Solid Diecasting Process

Chul Woo Park[1], Young Ho Kim[2]

[1] Dept. of Precision Mechanical Engineering, Graduate School, Pusan National University, Pusan, South Korea
[2] School of Mechanical Engineering, Pusan National University, Pusan, South Korea

ABSTRACT

In the Semi-Solid Diecasters design, a Semi-Solid Diecasters experiment has usually been carried out before producing new casts. At the Semi-Solid Diecasting stages, the runner-gate part has been always repeatedly corrected, which leads to a tedious processing time and high processing cost. Much experience is essential in manual assessment and if the design is defective, much time and a great deal of efforts will be wasted in the modification of the die.

In this study, a design system has been developed based on the design database. In addition, a gate experiment for the gating system design has been carried out to append the database. It is possible for engineers to make efficient gating system design of Semi-Solid Diecasting and it will result in the reduction of expenses and time to be required.

Key Words : Semi-Solid Diecasting , Gating System, Runner, Gate

1. Introduction

Recently, due to the environmental and energy problems, much effort has been spent worldwide for developing lightweight, high performance, and environmentally conservative parts and for reducing the processing steps in the automobile, aircraft, ship, and others industrial areas. At present, the conventional aluminum casting or forging process is a general way of producing lightweight parts. But in those processes, some of defects are found. Thus, the need of a new process for producing high performance parts is increasing.

The Semi-Solid forming is one of new methods for overcoming the defects produced in the conventional aluminum casting or forging process. In the case of the conventional Diecasting. In the case of the conventional forging process, the forming pressure is increasing, the forming of complex shape products is limited, and the production costs are increased by secondary machining. Due to those kinds of defects, Semi-Solid forming process using feed stocks coexisted the solid and liquid phase were proposed.

The Semi-Solid forming process has some of specific merits. In the view of microstructure, unlike dendrite structure produced in the conventional casting process, the globularized solid phase distributed in the liquid phase minutely and uniformly is produced in the Semi-Solid forming process. And this globularized structure can defects such as segregation or crack as solidifying. Also, the shrinkage and distortion can be diminished, and the net shape forming without secondary machining is possible because of the low quantity of liquid phase compared with that of conventional casting process. By net shape forming, good surface quality, high dimensional accuracy and the superior and uniform mechanical properties of products can be obtained. And also using high viscous material compared with liquid material used in the conventional forming process, the filling flow pattern is not turbulent but laminar, which dose not trap air in the products. By the low energy consumption compared with the conventional casting process, Semi-Solid forming has the merits, such as decreasing the thermal fatigue of the die, increasing the lifetime of the die, and so on. For this reason, Semi-Solid forming has been sharply developed, especially in the recent automobile industry in the world.

This study is focused on Semi-Solid Diecasting (SS Diecasting): one of the Semi-Solid forming processes. S. P. Midson[1] proposed the proper gate speed of SS Diecasting in the filling experiment for a plate-shaped die cavity, and investigated the influence of key process parameters on the quality of SS metal cast aluminum component. C. M. Wang[2] determined the optimal SS Diecasting process parameters by simulation. O. Hervieu[3] studied the flow pattern and gate speed in the SS Diecasting. M. Garat[4] proposed the specific physical and mechanical properties of SS Diecasting.

However, those researches were limited to the SS Diecasting process for specific product shapes, and application of the SS Diecasting die design to CAD/CAM system was hard to find. Accordingly, in of order to easily produce the lightweight, high performance, and high strength parts used as main parts of automobile and aircraft, the application of SS Diecasting die design to CAD system is necessary.

The general SS Diecasting die design includes selection of alloy materials, design of products, and gating system including the design of gate, runner, overflow and so on. But most of the SS Diecasting die designs were properly built for the specific products. And when SS Diecasting dies are to be designed, know-how based on experiment is very important, and a skilled worker is needed. Additionally, because SS Diecasting is a new process, a reliable database is insufficient. So in the case of SS Diecasting, die design was done by a trial and error method, yielding loss of time and cost. Especially in the gating system main part of die design, unlike a conventional Diecasting, the gating system of SS Diecasting has to be designed with consideration of the flow pattern when material alloy is filled into the cavity, solid fraction, viscosity, shear rate and so on. Those factors make it hard to design the gating system.

Consequently, the requirement that the system is built based on the data of know-how based on experiment is increasing and the application of the proper gating system design of SS Diecasting for various shapes of parts to CAD/CAM system is increasing. The system can solve the problems of much time and cost taken in gating system design of SS Diecasting and improve the productivity and the mechanical properties of parts in the SS Diecasting.

In this study, for the rational and efficient gating system design in the SS Diecasting, the database built on know-how based on experience and the rules and algorithms of the SS Diecasting gating system design were proposed, and the design standard of the SS Diecasting gating system was accomplished. Based on the rules, algorithms and data, the design system was programmed in AutoCAD using AutoLISP.

2. Gate Experiment

The determination of the gate is the most important part in the SS Diecasting gating design. If the gate size is too large and the ram speed is too low, the gate speed can not reach the proper speed, which is needed to complete the die cavity filling. If the gate size is too small and the ram speed is too high, the gate speed is so high to cause a turbulent flow in stead of a lamina flow. And a high gate speed makes the filling not by uniform forward flow but by back flow occurred after the main flow reaches the end of the cavity. For this reason, determination of the gate size and speed is an important factor in SS Diecasting die design. In order to find the rule of determination of the gate, a circle gate experiment was conducted.

Using the globularized material, A356, the influence of forming factors such as ram speed and gate area size, on the final products was identified, and based on this, the forming condition which can produce the satisfactory microstructure of the SS Diecasting products was found. From the results of the experiment, the forming characteristics was understood and the data of gate determination was produced.

2.1 Material in the experiment

For the circle gate experiment, A356 was used which was produced by MDT stirring in Pechiney French, and has globularized microstructure. The dimension of the feed stock is Ø80mm×H 80mm, and the chemical composition is shown in Table 1. To heat the feedstock, a 50kw induction heater was used.

Table 1 Chemical compositions of aluminum 356 alloy

	Al	Si	Cu	Mn	Mg	Zn	Fe	Ni
A356	rem	6.59	0.12	0.005	0.39	0.005	0.01	0.02

The heating temperature was 578℃ to result in 55% solid fraction, and to reduce the temperature difference between center and surface parts of the feedstock, a step heating process was used.

2.2 Experimental apparatus

For the convenience of die design and manufacturing, a simple vertical type die was produced for the experiment. The schematic drawing of the die set is shown in Fig. 1. The upper, low die, and punch were made of SKD61 heat-treated by HRC55. To heat the upper and low dies, a cartridge heater was used. For more accurate checking of the upper and low die temperatures, INCONEL 1.6 K-Type thermocouples were used.

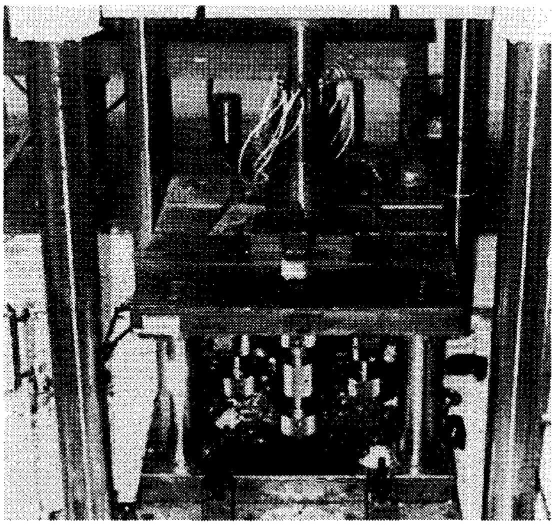
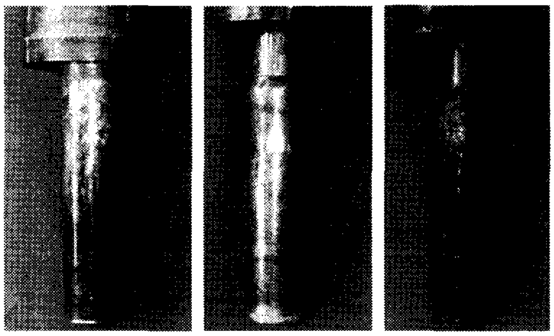


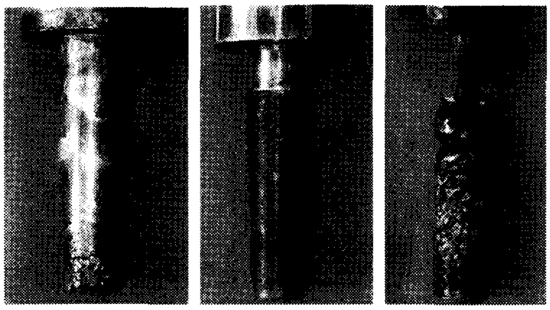
Fig. 1 Photograph of die set for gate experiment

2.3 Forming factors in the experiment

To identify the influence of forming factors on the final products, punch speed and gate area were selected as the forming factors. The die temperature was 250℃, the solid fraction was 0.55, and the punch speed was varied between 200mm/s and 100mm/s. In the cone-shaped cavity, the diameter of the gate was 40mm, and the diameter becomes smaller from top to bottom. The diameters of the gates were 40, 31.8, 18.3mm. The final products in the experiment are shown in Fig. 2. For each gate size and punch speed, the final products are shown in the figure. When the punch speed is low, the filling pattern is poor compared with that of high speed.



a) Photograph of products at 200mm/s

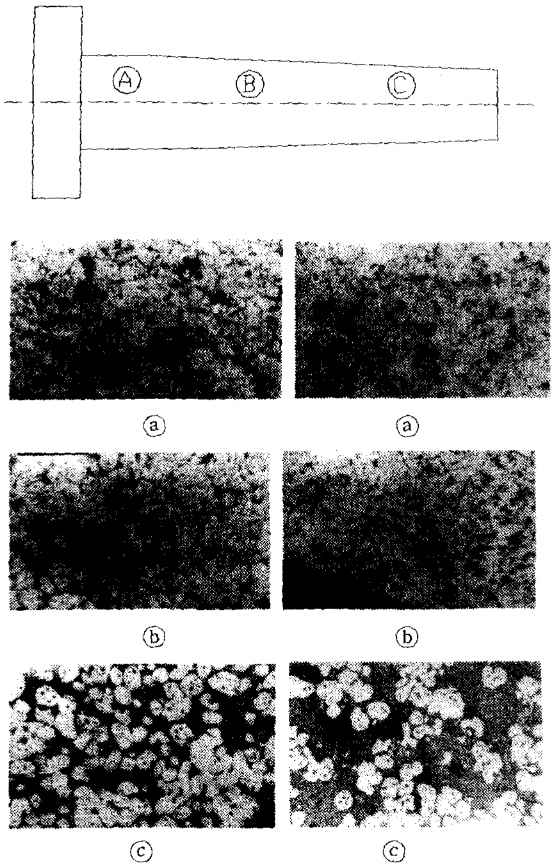


b) Photograph of products at 50mm/s

Fig. 2 Photograph of products

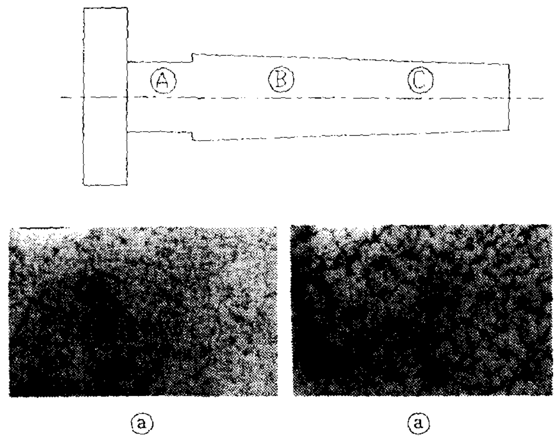
2.4 Evaluating the microstructure

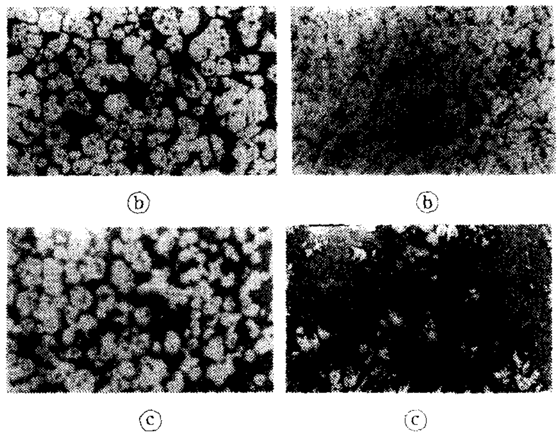
To investigate the microstructure, the specimens were obtained at three locations of the final products: gate parts, middle of products, and end of products. The magnifying ratio was 100, and in each part of products produced by different forming conditions, the photos of the microstructures are shown in Fig. 3~5. In the common feature of microstructure, the solid part is mainly located at the gate parts and the liquid part is mainly located at the end of product parts.



a) 200mm/s b)50mm/s

Fig. 3 Microstructure of each part in the gate of 40mm diameter

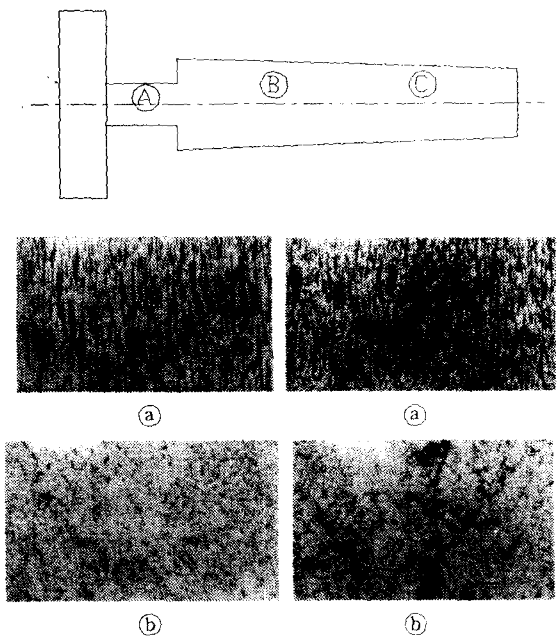


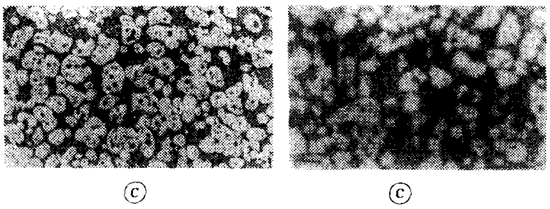


a) 200mm/s b)50mm/s

Fig. 4 Microstructure of each part in the gate of 31.8mm diameter

This phenomenon occurs due to the fact that liquid flows faster than solid.[5] When the punch speed is low, this phenomenon is more predominant, separation between solid and liquid is accelerated, and non-uniform products are manufactured. Thus, in the SS Diecasting, a high punch speed is desirable. In the case of the gate of 40mm diameter, desirable distribution of solid and liquid in the microstructure is obtained.





a) 200mm/s b)50mm/s

Fig. 5 Microstructure of each part in the gate of 18.3mm diameter

However, in the case of the gate of 31.8mm diameter effluence of liquid is excessive in the end part of products. In the case of 18.3mm diameter of gate, the filling is not completed, and the solid is compressed too much at the gate parts. Thus, it tends to produce non-homogeneous products.

In this experiment, the influence of the gate size and punch speed on the microstructure of the final products can be found. A bigger gate and higher gate speed can make more satisfactory microstructure.

3. Database

In this study, a database of material properties, shrinkage, gate speed, and size was built for the gating design system of SS Diecasting.

3.1 Material DB

The metal alloys produced by different company have slightly different chemical compositions. Additionally by a stirring process or other processing condition, the properties of the metal alloys become different, even though the same name of materials are used. Thus, selecting proper material properties is very important to determine the processing conditions. In this system, the basic information of SS metal alloys is proposed, such as the chemical composition and the mechanical and physical properties. In the system, material properties are changed, depending on temperature. In this study, by construction of a material database, the selection of material according to the user requirement is more efficient.

Proposed materials for the SS Diecasting in this system are Aluminum metal alloys. The database based on Aluminum alloys such as A356, A357 and A319, which are generally used in Aluminum SS Diecasting. The data of metal alloys was obtained from the companies producing those kinds of metal alloy. The mechanical properties such as ultimate tensile stress, tensile stress, yielding stress, elongation, and hardness and the physical properties such as specific gravity, density, and thermal conductivity were used to construct the material database. The temperatures of Solidus line and Liqudus line were proposed, and in this temperature range, solid fraction, specific heat and mean thermal expansion coefficient were included. This database can make it easy to select the processing condition, which is one of the user requirements, check the possibility of forming by identifying the solid fraction in temperature, and find the temperature corresponding to the propers solid fraction.

3.2 Shrinkage DB

The metal alloy in the SS Diecasting shrinks after the cavity filling is completed. If the shrinkage cannot be estimated before the manufacturing of a die cavity, the exact dimension of the product will not be obtained. When the shrinkage is estimated too much, the process brings about the loss of time and cost by material waste and lots of additional machining. When the shrinkage is estimated too little, the desired product dimension cannot be obtained. Therefore, the exact estimation of the shrinkage depending on temperature is very important for producing a desired part.

The rule of shrinkage is shown below.

$$\triangle L = \frac{\Delta l}{L_0} = \alpha(t_s - 20) - \alpha_f(t_f - 20)$$

$$Factor = 1 + (\Delta L \times S)$$

α : thermal expansion coefficient of material

t_s : temperature of material in forming process

α_f : thermal expansion coefficient of die

t_f : temperature of die in forming process

s : modification factor

Except the modification factor s, the rule is the same as that applied to a general casting for calculating the shrinkage.[5] From the shrinkage data, the shrinkage in the SS Diecasting was determined, and modification factor is selected as 0.5 in this system.

3.3 Gate Design DB

The most important part is the gate design in the SS Diecasting die design. Because the feedstock composed of solid and liquid phases is used in the SS Diecasting, filling time, cooling time, and gate speed are different from those in the conventional Diecasting die design. The selection of proper gate area size for producing the laminar flow is an important factor in producing the products.

By the filling pattern and gate speed, the area of the gate is determined in the gate design. In this study, two types of gates (square type gate and circular type gate) were proposed, and the property of forming for the gate speed and area was investigated.

3.3.1 Circular Gate

In the case of the cylindrical shape products, the square type gate which is generally used is hard to apply, so the circular type gate is needed. The circular gate experiment was conducted for investigating the influence of the gate speed and area on forming.

The result from the experiment shows that the best filling pattern without causing folding and air entrapment is occurred when the gate size is equal to the cross-section of the products. In practice, if this is not possible for dies of commercial interest, a gate size as close to the full width of the products as possible is optimal, and the gate should be as thick as the product, because a thinner gate produces a poor flow pattern. A sudden change in the gate area has to be avoided for uniform filling from gate to end parts. Additionally, the filling pattern is poor if the area ratio between gate and runner is too large.

From the experiment, the critical speed for producing a laminar flow in the circular gate is lower than that in the square gate. The reason for this phenomenon is that the contact surface between material and die in the circular gate is smaller than that in the square gate. The small contact surface can produce longer cooling time and better fluidity.

3.3.2 Square Gate

From the previous study[6] of square gate experiment, the gate determination factor in the square gate was obtained.

Based on the result of the experiments, the best flow pattern was clearly obtained when the gate size was equal to the cross-section of the product. In practice, if this is not possible for dies of commercial interest, a gate as close to the full width of the casting as possible is optimum. In addition, the gate should be as thick as the casting for two reasons. First, poor flow behavior can occur when the gate is significantly thinner than the casting. Second, if the gate is thinner than the casting, it will solidify prior to the casting, preventing the feeding of the solidification shrinkage.

4. System construction

The proposed SS Diecasting gating design system in this study is divided into two sections and the layout of the whole system is shown in Fig. 6.

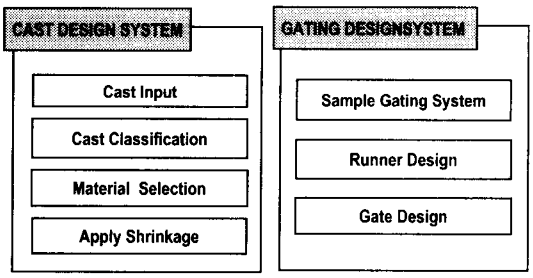


Fig. 6 Layout of the gating system design

4.1 Cast Design System

The second section is Cast Classification. This section is for classifying the model shape, and proposes 8 items in order to classify the input part model. In this process, the system can identify the shape code of the input part model, and this code will be used to decide the Preliminary gating system, Gating Design System, which will be discussed later. A flow chart of the classifying is shown in Fig. 7

The 8 classifying items are illustrated in Fig. 8.

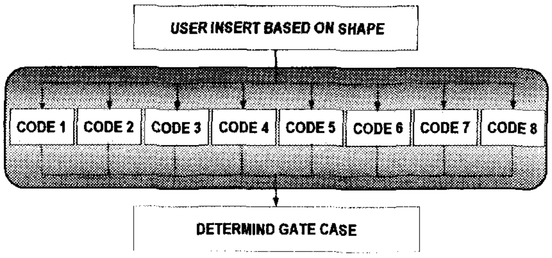


Fig. 7 Layout of gating system design

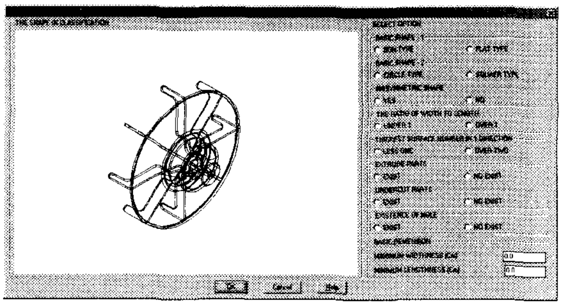


Fig. 8 Window of cast classification

4.2 Gating System Design

This section for designing the gating system is divided into three sections, as shown in Fig. 9. The first section is Preliminary Gating system to propose the generalized gating system corresponding to the shape characteristic. The second section is Gate Design to determine the gate size and the relation between gate and runner, and the last section is Runner Design to design a specific runner shape.

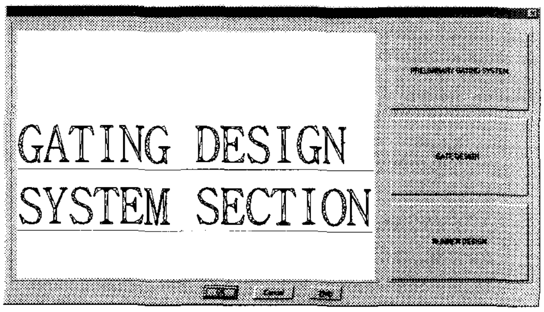


Fig. 9 Window of Gating Design System

5. Application

The total dimension of a model is 130mm×200mm ×140mm, but the real thickness is 10mm at bottom and 30mm at the side. The metal alloy for the break cover is A319. The required tensile strength of the products is over 250Mpa. And the process of the SS diecating gating system design is as follows:

1) Using PRO-ENGINEER, the product is 3D modeled to a wire frame shape. In order to use it in the system, the model file is converted to an IGES file, as shown in Fig. 10.

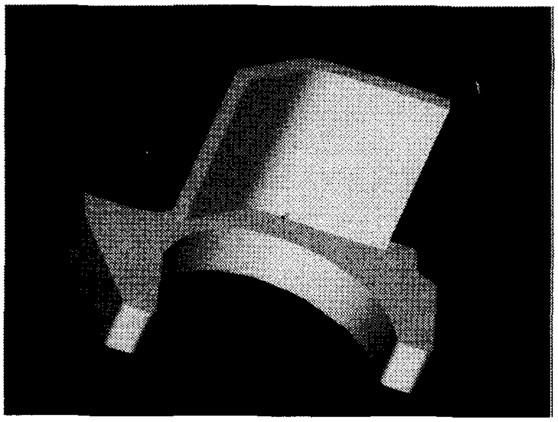


Fig. 10 Modelling of A/C mounting bracket

2) Selecting the CAST DESIGN SYSTEM. And then the model is inputted in the CAST INPUT, and the viewpoint is changed. Input the proper marking to items considering the model shape in the CAST CLASSIFICATION, as shown in Fig. 11.

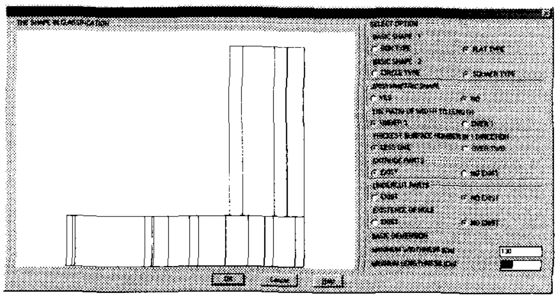


Fig. 11 Window of cast classification

3) Identify the characteristics is of SS material in the MATERIAL SELECTION, and select the proper

material (A319) satisfying the requirement. Select the temperature 590℃, and check the solid fraction 50% for the SS Diecasting, as shown in Fig. 12.

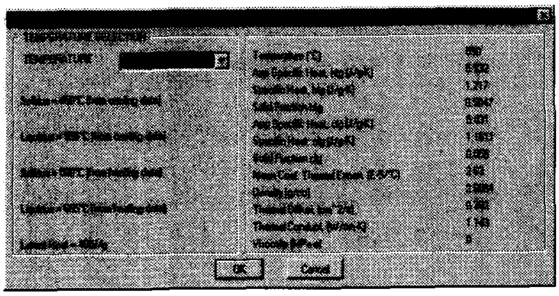


Fig. 12 Window of material selection

4) Check the temperature, solid fraction and thermal expansion coefficient of material, and input the temperature and thermal expansion coefficient of the die and modification factor, as shown in Fig. 13. The thermal expansion the coefficient of die is determined as 1.05×10^{6} (general high carbon steel), the die temperature is 300℃, and the modification factor is 0.5 because the solid fraction of the material in the process is close to 50%. After inputting all values, the model scale is changed automatically.

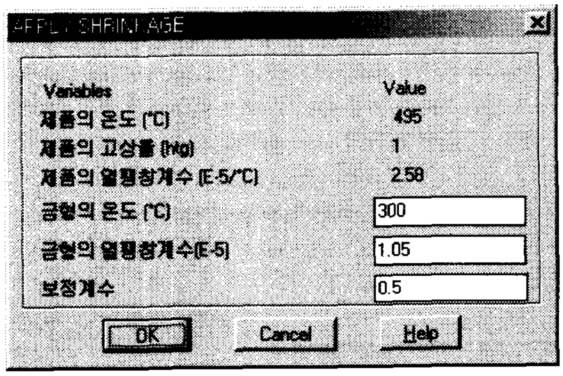


Fig. 13 Window of apply shrinkage

5) Confirm the sample gating system for the SS Diecasting in SAMPLE GATING SYSTEM as shown in Fig. 14.

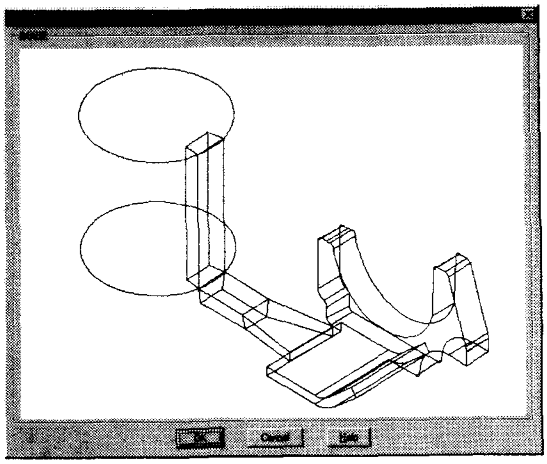


Fig. 14 Window of example gating system

6) Input values for gate speed, filling time, volume of cast, and etc. in the GATE DESIGN, as shown in Fig. 15. The Square gate is selected. And the gate speed is 5m/s and the filling time is 0.03s. From the relation between gate and runner, the gate number is 1, the ratio of the runner to the gate is 2, and the aspect ratio of runner is 2. The thickness of the gate is 10mm, and the width of the gate is 57mm.

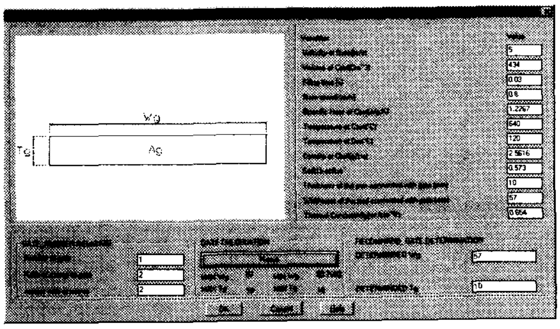


Fig. 15 Window of gate design

7) The model is rotated and positioned properly as shown in Fig. 16. And the distance between the sprue and the base point of the model is 200mm.

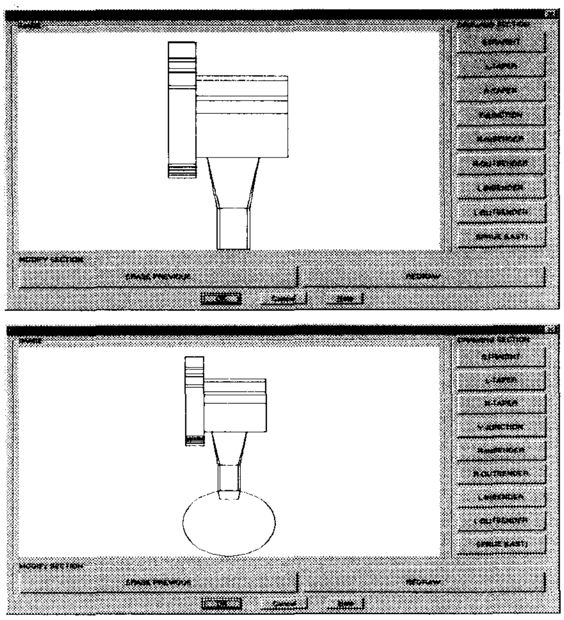


Fig. 16 Window of runner design

8) The final gating system design is shown in Fig. 17.

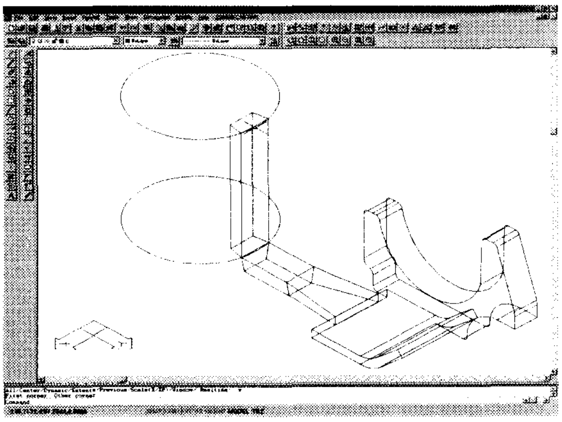


Fig. 17 Window of final gating system design

6. Conclusion

This system was developed for overcoming the problems of a trial and error method and was focused on designing the Gating system and applying the gating system design to CAD/CAM as a basic study of Semi-Solid Diecasting die design system. The system is built from selecting the Semi-Solid material to designing the specific runner, and the database for the Semi-Solid Diecasting gating system design is built by the data collected from know-how in work field, various materials of the domestic and foreign references, and experiments.

The following conclusions are made in this study.

1) In the CAD environment, the Auto design system for Gating system of the Semi-Solid Diecasting die design was developed.

2) Chemical composition, mechanical and physical properties for various temperatures of Semi-Solid materials were collected and the database was built.

3) By the experiment, the influence of the gate area and speed on the products was clarified.

4) By collecting data and from experiment, knowledge of design for the Semi-Solid Diecasting gating system design is built into the database.

5) The system is organized in such a way that for ease of runner design, the model was classified, by the shape exposition from the classification, the Preliminary Gating System was proposed, and the detail runner was designed.

Acknowledgements

The authors would like to acknowledge the cooperation of the Engineering Research Center for Net Shape and Die Manufacturing at Pusan National University.

Reference

1. Midson, S. P., Thornhill, L. E. and Young, K. P., "Influence of key Process Parameters on the Quality of Semi-Solid Metal Cast Aluminum," Component 5th International Conf. On Semi-Solid Processing of Alloys and Composites, pp. 181-188, 1998.
2. Wang, C. M., Nickodemus,G. H., Creeden,T. P., "Determining Optimal Semi-Solid forming Process Parameters by Simulation," 5th International Conf.

On Semi-Solid Processing of Alloys and Composites, pp. 327-334, 1998.
3. Hervieu, O. and Collt, J., "Die-casting of light metal in the Semi-Solid state : Study of the PID process," 4th International Conf. On Semi-Solid Processing of Alloys and Composites, pp. 283-289, 1996
4. Garat, M., "Aluminum Semi-Solid Processing : From the Billet to the Finished Part," 5th International Conf. On Semi-Solid Processing of Alloys and Composites, pp. xvi-xxxi, 1998.
5 Chen, C. P., et al., "Semi-Solid Deformation of Non-dendritic Structure -I. Pheno- menological Behavior," Acta mater. Vol. 45, No. 5, pp. 1955-1968, 1997.
6. Young, K. P., Ballwin Mo., "Process for preparing a slurry structured metal composition," United State Patent, No. 4,565,241[5].
7. Midson, S. P., Minkler, R. B., Brucher, J. G., "Gating of Semi-Solid Aluminum Castings," 6th International Conf. On Semi-Solid Processing of Alloys and Composites. pp. 67-72, 2000.
8. Midson, S. P., Thornhill, L. E. & Young, K. P., "On Semi-Solid Processing of Alloys & Composites," 5th International Conf. Colorado School of Mines, pp. 181, 1998.