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Runner design optimization based on CFD simulation for a die with multiple cavities

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ABSTRACT

As part of the NADCA HyperCast project, computational fluid dynamic (CFD) methods were applied to analyze a high pressure die casting (HPDC) die containing six cavities producing various test specimen. As is typical, each specimen cavity is connected to the main runner by a separate branch runner. The connection of the branch runners to the main runner strongly influences the filling ability of each specimen cavity. The purpose of this study was to analyze the influence of the runner trajectory and directional changes on the ability to smoothly fill the cavities. CFD simulation was used and different runner designs were compared. An improved design was proposed and some general observations about the effects of runner geometry on pressure distribution and fill time are provided.

KEYWORDS: CFD, HPDC, Hypercast, Runner design, Simulation.

INTRODUCTION

In order to produce high quality parts with high pressure die casting, computer aided simulation has been used to optimize mold designs. Finite difference (differential), finite volume and finite element methods have been used in the filling process simulation and significant progress has been made for general problems[1-3]. Further work on mold design optimizations is still desired to address specific issues.

In die casting, the die often has more than one cavity with multiple cavities producing the same or different parts. Multiple cavities require the application of branch runners connecting to a main runner. The design of the runner system has always been a topic for die casting, since it is important for the designer to ensure that multiple cavities start filling at the same time and have the same fill time. A key factor in the design is to adjust the cross section area of each branch runner according to the cavities' volumes; however, this may not be enough to fill the cavities simultaneously. The angle between the branch runner and the main runner has been observed to have effects on the filling pressure, filling time and residual stresses[4-6], but the observations were limited to very simple lab level die design rather than practical castings.

This work, as part of the NADCA HyperCast project, analyzed a high pressure die casting die design containing six cavities, producing six different test specimens as shown in Figure 1. The design of the runner system was studied using computational fluid dynamic (CFD) methods. The filling pattern of each (specimen) cavity was strongly influenced by the connection pattern of the branch runners to the main runner. In the original design, each branch runner was connected to the main runner almost perpendicular to the sides of the main runner. This design generated uneven filling patterns for the specimen cavities. A modified design was then proposed, where the main runner was tapered and each branch runner connected by a small inclined angle towards the main streamlines. CFD indicated that the modified design significantly improved the filling pattern by effectively balancing the pressure distribution and filling time among different cavities.

PROBLEM STATEMENT

In this work, the filling process was simulated using CFD software Flow3D[a] V9.4. A solid model of the die (Figure 1) was first exported to STL files and then imported to Flow3D. In order to accurately simulate the filling process, the whole casting mold and shot sleeve were included in the simulations. A plunger propelled metal filling process was simulated. The speed of plunger was 0.77m/s for slow shot and 1.55m/s for fast shot. The selected casting alloy was aluminum A380 and during the simulations the viscosity was assumed to be constant (0.0012 Pa.s).

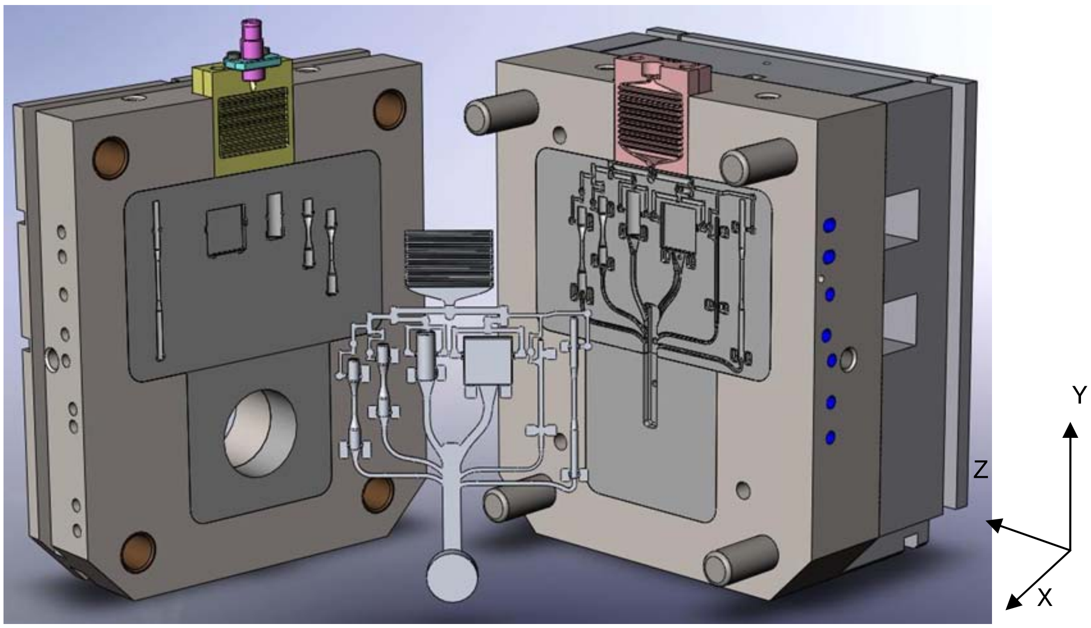
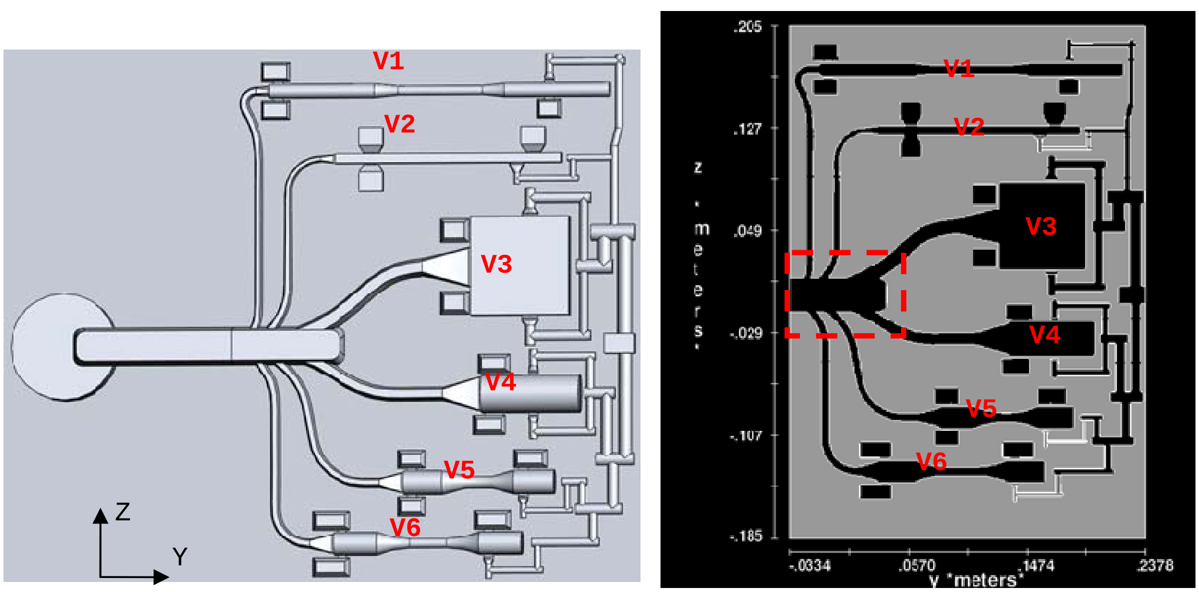


Figure 1- CAD design of die assembly and casting part. Gravity direction is along the negative y direction. Shot sleeve and plunger are aligned along the x direction.



(a). CAD design of complete casting.

(b). cross section at parting surface of ejector insert in computer model.

Figure 2- CAD design of complete casting (a) and cross section at parting surface of ejector insert in computer model (b) for original runner design.

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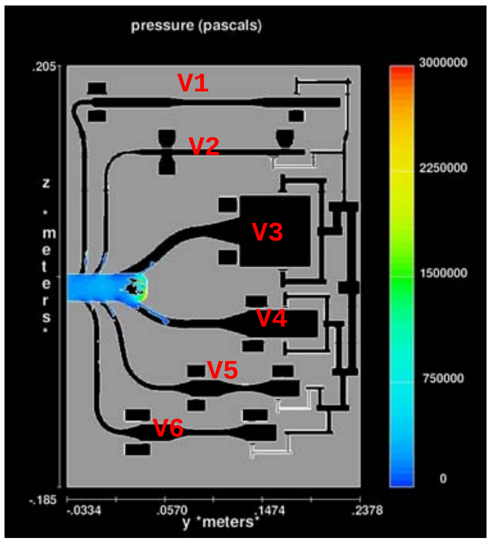
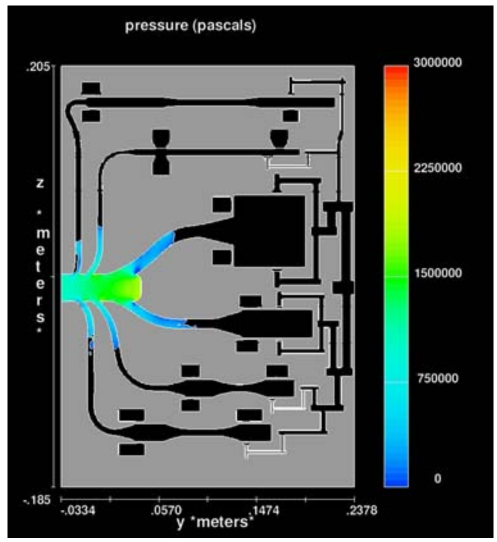
[a] Flow3D is registered trade mark of Flow Science.

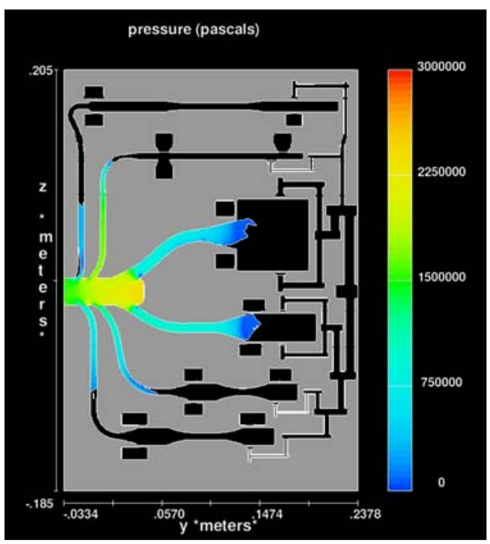
Figures 2a and 2b, respectively, show the CAD design of the casting and the cross-section plot of the Flow3D model at the parting surface of the ejector insert. As can be seen from these figures, there are six cavities producing various test specimens with different shape and volumes. Each cavity is connected to the main runner by a separate branch runner. The cross sectional area of each branch runner has been adjusted according to the volume of the specimen cavity. In the original die design, as shown in Figure 2b, the main runner is marked in the red dashed box. It has a rectangular design with a constant cross section area along the filling direction (y). All of the branch runners are connected almost perpendicularly to the sides of the main runner.



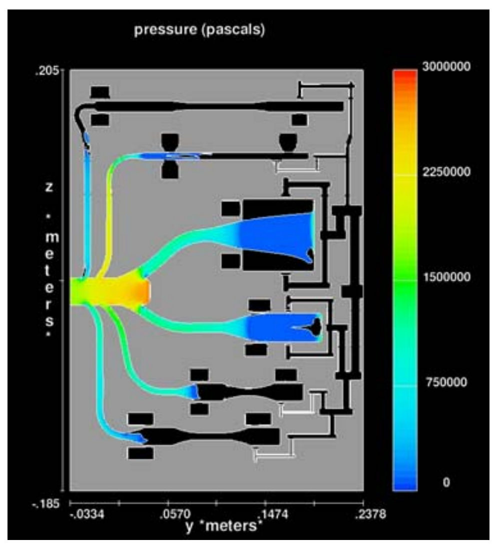
(a) TP1 - Main runner filling.



(b) TP2 - Branch runner filling.



(c) TP3 - Cavity enter.



(d) TP4 - Cavity filling.

Figure 3- Computed pressure contour along parting surface at different time point (TP) as metal filling the die cavities for original runner design.

Figures 3a, 3b, 3c, 3d show the filling pattern of the original design at four time points (TP) and the filling patterns are color coded with respect to pressure magnitude. The total die cavity filling time, measured from the time the metal front enters the main runner until all cavities are filled, is about 0.040s and the four time points selected are 0.011, 0.013, 0.015, 0.017s. At the first time point (Figure 3a), metal begins to fill the main runner and the metal front hits the end (at right) of the main runner. This induces a recirculation and high back pressure. No branch runner has been filled up to this moment.

At the second time point (Figure 3b), metal begins to fill the branch runners after the main runner is filled. The filling processes for branch runners, however, are not even. The two large branch runners located close to the end (at right) of the main runner are filled first and at the fastest rates, while the two thin branch runners located farthest are filled last and at the slowest rates.

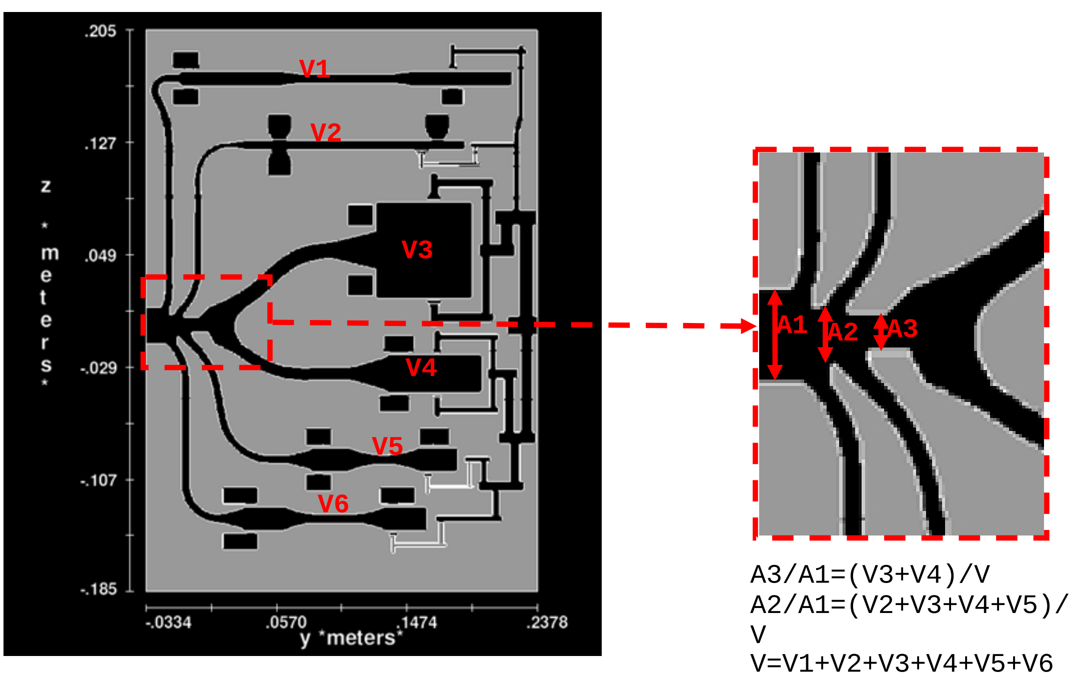
At the third time point (Figure 3c), the metal front begins to enter the specimen cavities. The third time points are significantly different for each cavity. As the metal began to fill the two cavities in the middle (V3 and V4), the metal front was still far away from the entrance to the cavities V1 and V6 whose runners are the last to fill.

The fourth time point (Figure 3d) shows the process of metal filling of specimen cavities at a later time. Besides the filling time difference already noted in Figure 3c, the pressure patterns are different in each branch runners as well. For the branch runners of cavities V3 and V4, the pressure is distributed similarly and with a relatively high value. For the branch runners of cavities V1 and V6, the pressure is very low. This reveals the fact that the branch runners of V1 and V6 are not fully filled even after the cavities V3 and V4 are half-way filled.

These CFD results partly explain typical problems observed during production. Standard rules of thumb suggest that to produce high quality HPDC parts: the cavities should be filled at approximated the same time; the filling pattern in each branch runner and cavity should be similar; and recirculation should be avoided in the main runner. In order to address these issues in the design, a modified runner design was drawn and the results of the simulations were compared to the original.

MODIFIED RUNNER DESIGN

A modified main runner design was proposed to improve the filling pattern and correct the issues observed above. The modified design is shown in Figure 4. The main runner was tapered and each branch runner was connected to main runner at a small angle towards the main streamlines. The shape of main runner was changed to a tapered style where the cross section area was reduced from entrance to the end of runner. The details are plotted in the enlarged sketch in Figure 4b. The cross section area reduced according to the ratio of the specimen cavity volumes to the total cavity volume. The cross area at the entrance (left side) was chosen to be the same as the original design and represented by A1. After the first two branch runners, the cross area reduced to A2 and A2/A1=(V2+V3+V4+V5)/V, where V=V1+V2+V3+V4+V5+V6. The cross area further reduced to A3 after the next two branch runners and A3/A1=(V3+V4)/V. In addition to the reduction in the cross section area, the end of main runner was also changed. The rightmost two branch runners were connected to the main runner end directly instead of to the sides and the cavity was thus removed from the end of the main runner. This is counter to the practice of some designers who use the blunt end of the runner as a “trash” collection point but, as will be shown, improved pressure and flow fields result.

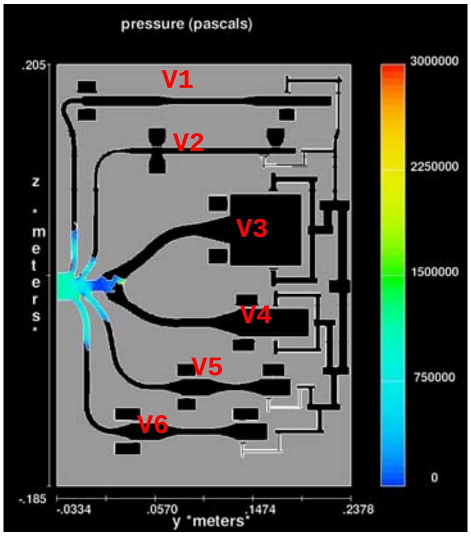


(a) Cross section plot at parting surface.

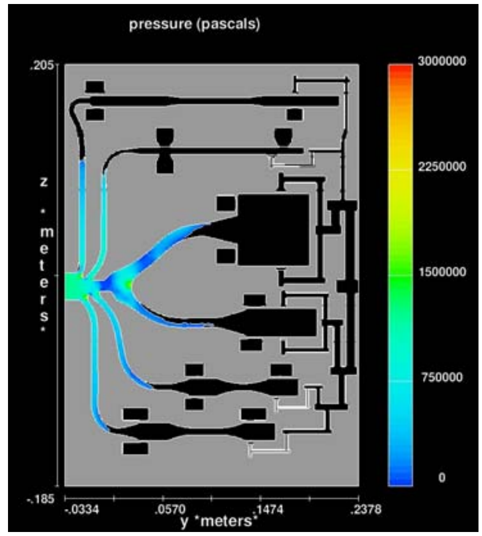
(b) Enlarged plot of modified runner design.

Figure 4- Cross section at parting surface of ejector insert for modified runner design.

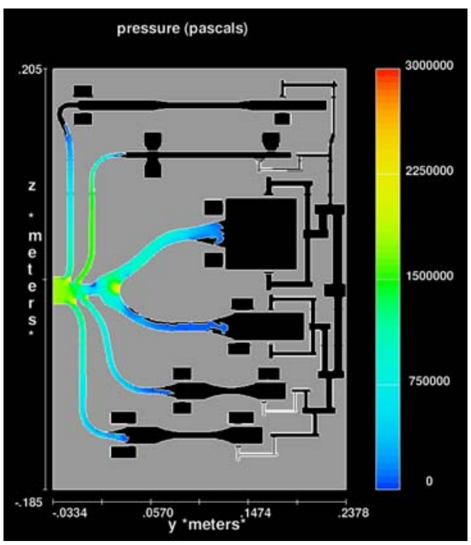
The modified runner design was then simulated and the results are shown in Figures 5a, 5b, 5c, 5d. The four time points selected for the modified design are 0.01, 0.013, 0.014, 0.017s. At the first time point (Figure 5a), the metal begins to fill the branch runners while filling the main runner. Neither recirculation formation nor high back pressure is observed. At the second time point (Figure 5b), the branch runners are filled with similar speed and have similar pressure distributions. At the third time point (Figure 5c), the metal front begins to enter the six specimen cavities at almost the same point in time. At the fourth time point (Figure 5d), the specimen cavities are filled at a similar rate and have similar pressure distributions.



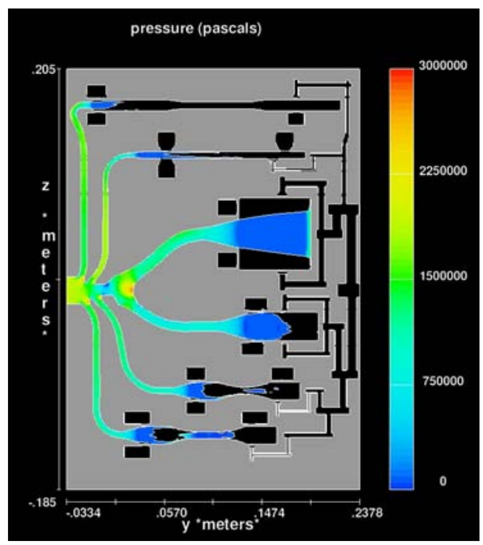
(a) TP1 - Main runner filling.



(b) TP2 - Branch runner filling.



(c) TP3 - Cavity enter.



(d) TP4 - Cavity filling.

Figure 5- Computed pressure contour along parting surface at different time point (TP) as metal filling the die cavities for modified runner design.

In order to quantitatively examine the effect of modified runner design on the cavity entrancing time, the cavity entrance time was compared. For the original design, the difference in the entrance time between first filled cavity (V3) and the last filled cavity (V1) was 0.004 sec, while for the modified design the difference was within 0.001 sec. The total die cavity filling time, as mentioned before, is approximately 0.040s, and the filling time of the branch runners and the test specimens is approximately 0.030s. The modified design therefore significantly reduced the difference in the filling time for different specimen cavities.

The computation results indicated that the modified runner design effectively removed the issues observed in the original design, in that the filling time and the pressure distribution were adjusted to be similar for different specimen cavities. This would help facilitate the HPDC operational control and generate specimens with uniform quality.

In the modified design, only the connections between branch runners and the main runner were considered. Further modification can be applied to the design of each branch runner, which may include the joint angle, the path and the cross-section shape. In addition, the problem of the dirty metal front should be addressed in the following modification. The dirty metal front is collected in the blunt end of the main runner in the original design. The application of the blunt end, however, is not adequate to trap all the dirty metal in the modified design because the metal front is split into branch runners instead of being held in the main runner. The design needs 'trash' collection for each branch runner. The above problems require additional optimization and analysis.

CONCLUSION

In this work, computational fluid dynamic (CFD) method was used to study the effect of runner design on the filling patterns of a HPDC die with six specimen cavities. Two runner designs were compared: one has constant cross-area main runner; the other has a tapered main runner with cross-area reduced proportional to the cavity volumes' ratios. The simulation results revealed that the connection of the branch runners to the main runner strongly influences the filling ability of each specimen cavity. The application of the tapered cross-sectional area main runner design significantly improved the filling pattern in that filling time and pressure distribution were well balanced among specimen cavities with different volumes. If nothing else, these results confirm that many of the rules of thumb and design guidelines taught by NADCA do in fact result in better pressure fields in the die and more balanced fill patterns.

ACKNOWLEDGMENTS

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REFERENCES

1. Cross, M., K. Pericleous, et al., "Computational Modeling of Mold Filling and Related Free-Surface Flows in Shape Casting: An Overview of the Challenges Involved," *Metallurgical and Materials Transactions B*, vol 37B, P879-885B (2006).

2. Jeong, J. H. and D. Y. Yang, "Application of an Adaptive Grid Refinement Technique to Three-Dimensional Finite Element Analysis of the Filling Stage in the Die-Casting Process," *Journal of Materials Processing Technology*,vol 111, P59-63 (2001).

3. Kim, C-H., Kwon, T. H., "A Runner-gate design System for Dies," *Materials and manufacturing Process*, vol 16, issue 6, P789-810 (2002).

4. Sulaiman, S., Keen, T.C. "Flow Analysis along the Runner and Gating System of a Casting Process," *Journal of Materials Processing Technology*, vol 63, P690-695 (1997).

5. Thai, C. C., Lim, J. C., "A runner-optimization design study of a die-casting die," *Journal of Materials Processing Technology*, vol 84, P1-12 (1998).

6. Thai, C. C., Lim, J. C., "The optimal position for the injection gate of a die-casting die," *Journal of Materials Processing Technology*, vol 86, P87-100 (1998).