Design of die casting process of top cover of automobile generator through numerical simulations and its experimental validation

J.-H. Chen*[1], W.-S. Hwang[1], C.-H. Wu[1] and S.-S. Lu[2]

In this study, die casting of the top cover of an automobile generator made of aluminium alloy is designed with the assistance of the numerical simulation tool ADSTEFAN. Die casting with an original design of the single runner system was investigated, and casting defects were found on the surface. Fluid flow and solidification heat transfer were simulated for this particular die casting design. Casting defects similar to those found in the investigation were predicted using filling time, temperature distribution and residual gas flow pattern obtained from numerical calculations. Results show that the numerical simulation system is accurate and reliable. With detailed information of the casting process obtained from the simulation, an improved die casting design that uses a double runner system is recommended. Numerical simulation was conducted on the improved design, and no casting defects were found. The improved casting design was implemented, and sound casting was obtained.

Keywords: Die casting, Numerical simulation, Experimental validation

This paper is part of a special issue of papers selected from MCSP8, the 8th Pacific Rim Conference on Modeling of Casting and Solidification Processes

Introduction

Aluminium alloys have attracted a lot of research interest due to their light weight, good electrical and thermal conductivities,[1] high reflectivity of heat and light, fine surface finish, high resistance to corrosion under various service conditions and ease of processing.[2,3] These unique characteristics make aluminium alloys a versatile engineering material which is widely used in various industries, such as transportation equipment and precision machining. The application of aluminium to lightweight aircraft and automobiles could significantly reduce CO_2 emissions. Aluminium alloys can be cast using all known foundry methods.

In the past, the design of die casting moulds and the parameter settings of the die casting process were determined based on the experience and required follow-up tests and modifications. These processes are time consuming and expensive.

In order to reduce the defect rate of products, computer aided engineering analysis techniques and computer aided design (CAD) are used to optimise process conditions and mould design. In the die casting process, this technology reduces trial and error, shortens product development, improves quality and reduces material consumption.

Many computer aided engineering software packages are used in mould design. Many examples confirm that mould design can be optimised and that the casting quality can be significantly improved using numerical simulation. However, a common phenomenon in the analysis process is to pursue and demonstrate the numerical simulation accuracy, without deeply studying the causes of negative phenomena on casting. This was also the main appeal of this study.

In the present study, numerical simulation is used to predict the location and type of defects in an existing casting mould. The cause of defects is investigated to improve the design of the casting mould.

Simulation system

Cold chamber die casting was used to manufacture the top cover of an automobile generator. A mould designed based on experience was investigated, and the defects were found on the surface of the casting.

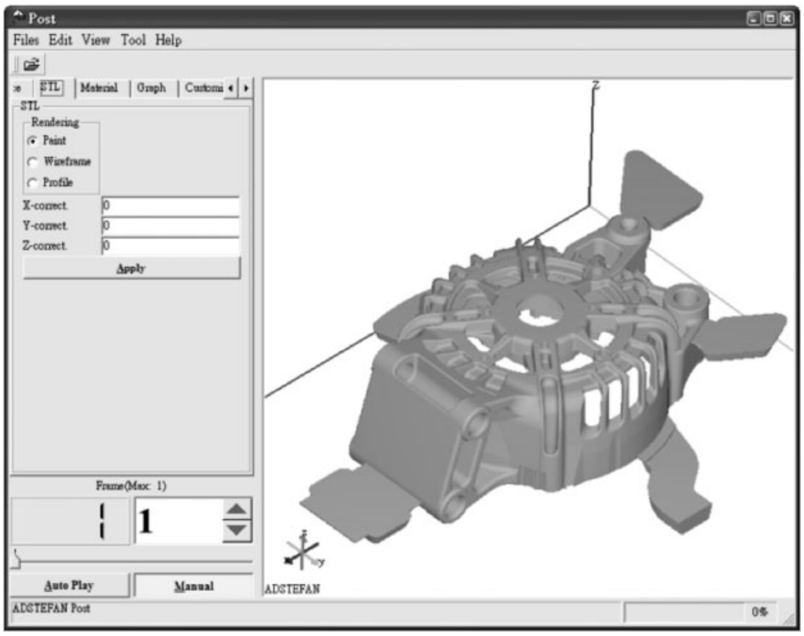
The software package ADSTEFAN (Hitachi Ltd) is used in this study. ADSTEFAN, which is based on the finite difference method, can be used to measure various parameters, such as fluid flow, temperature distribution of the fluid, residual gas in the fluid, heat transfer and heat stress of the mould, solidification process and microstructure of casting. ADSTEFAN was used to verify the formation of defects that simulate the results of fluid flow, temperature distribution and residual gas.

Before numerical simulation, CAD software (Solid-Edge) was used for the three-dimensional modelling of the casting, including the runner. The model in STL file format was imported into the simulation software, as shown in Fig. 1.

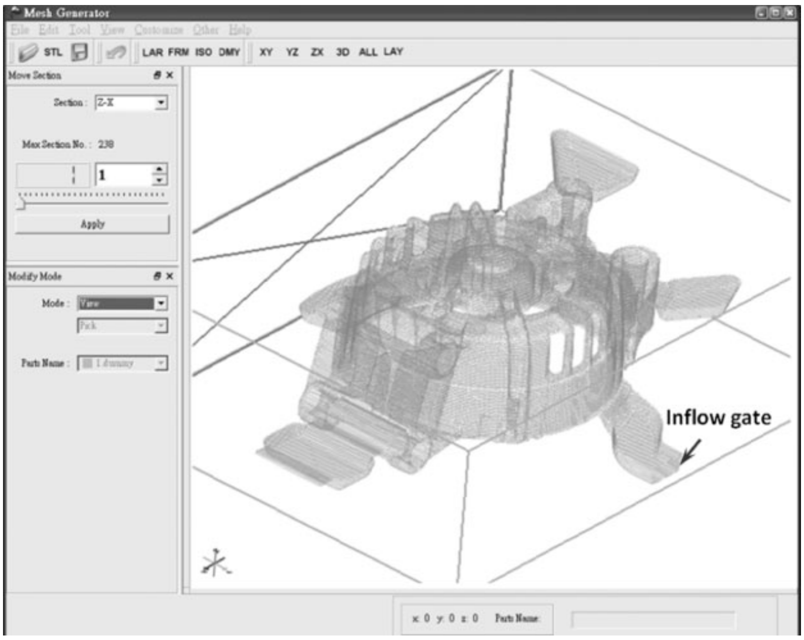
[1]Department of Materials Science and Engineering, National Cheng Kung University, Tainan City 701, Taiwan
[2]Tovonn Technology Corporation, 8F.-6, No. 296, Sec. 4, Xinyi Road, Da'an District, Taipei City 106, Taiwan

*Corresponding author, email angus.prosim.ncku@gmail.com

© 2011 W. S. Maney & Son Ltd.
Received 5 July 2010; accepted 23 December 2010
DOI 10.1179/136404611X13001912813906



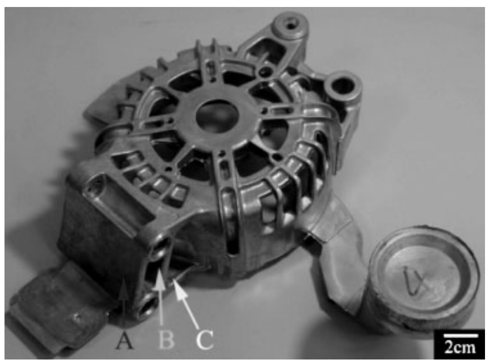
1 File (STL) of top cover of automobile generator imported into ADSTEFAN software



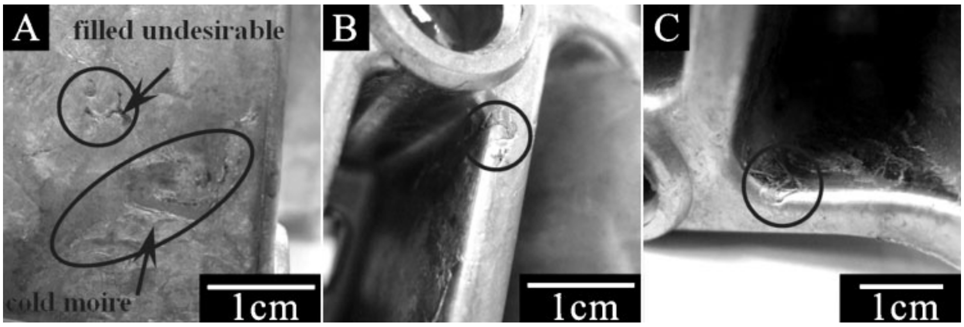
2 Mesh and position of inflow gate

The next step was producing the mesh. The CAD modelling units and the mesh size were first set. The mesh size was set to 1 mm^3 per unit, and the number of grids was calculated to be 6 689 610. The results are shown in Fig. 2. The inflow gate illustrates the position for the molten metal to flow into the die cavity.

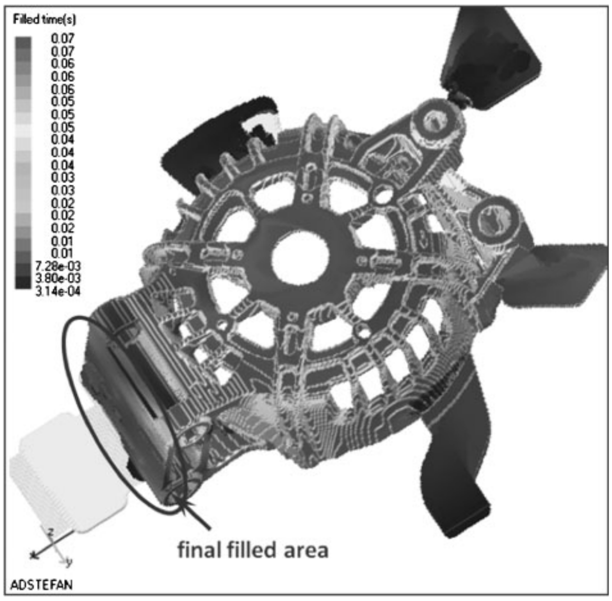
The material physical properties of the hot tool steel mould (SKD61) and the molten alloy (ADC12) were set, as shown in Table 1. The parameters of the die casting process are shown in Table 2. The parameters of low and high speeds of the inflow gate refer to the speed conversion from low to high pressure as the die casting process.



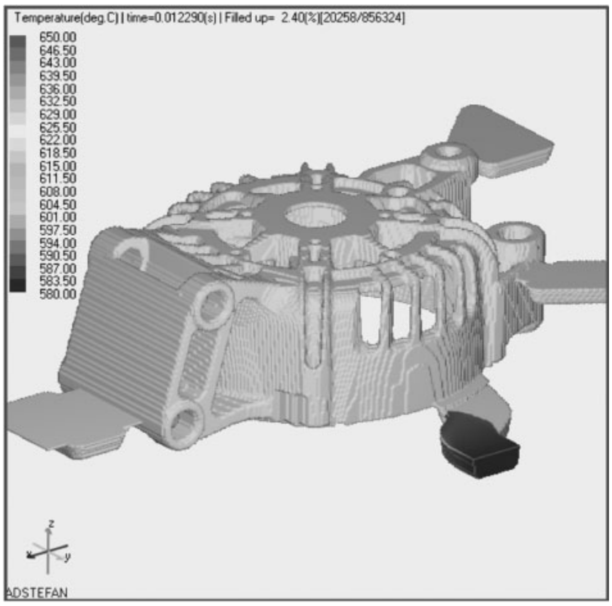
3 Casting using single runner system



4 Defects on surface of die casting of single runner system



5 Filling time results of die casting of top cover of automobile generator with single runner system



6 Fluid flow results and temperature distribution at filling time of 0·0123 s

Table 1 Physical properties of SKD61 mould and ADC12 alloy

	Solidus/ K	Liquidus/ K	Density/ kg m^{-3}	Kinem_vis/ m^2 s^{-1}	Latent heat/ J kg^{-1}	Heat capacity/ J kg^{-1} K^{-1}	Thermal conductivity/ W m^{-1} K^{-1}
SKD61	…	…	$7{\cdot}8\times10^3$	…	…	418·68	42·6768
ADC12	793·15	853·15	$2{\cdot}8\times10^3$	1×10^{-6}	393 559·2	1004·832	96·232

Table 2 Boundary conditions for ADSTEFAN

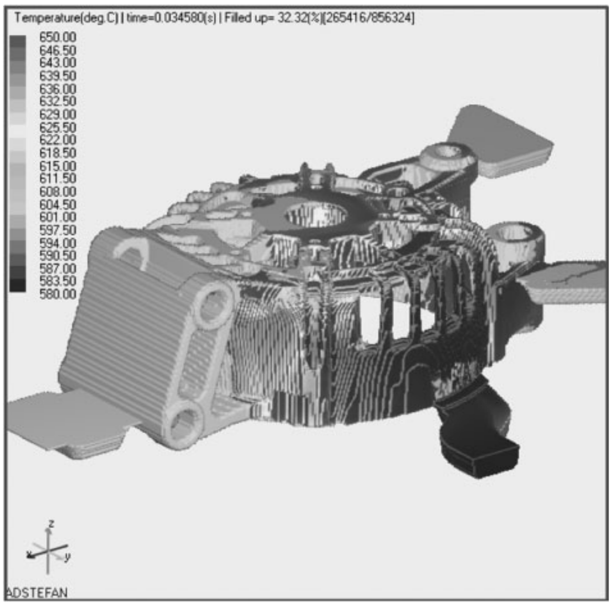
Initial temperature of mould/K	473·15	Inflow gate (low speed)/m s^{-1}	3·09
Material of mould	SKD61	Inflow gate (high speed)/m s^{-1}	24·72
Initial temperature of molten alloy/K	923·15		

Table 3 Composition of ADC12

Elements	Cu	Si	Mg	Zn	Fe	Mn	Ni	Sn	Al
Content/wt-%	1·5–3·5	9·6–12	0·3	1·0	0·9	0·5	0·5	0·3	Remainder

Table 4 Process parameters of die casting in this study

Initial temperature of mould/K	473·15	Die casting velocity (low speed)/m s^{-1}	0·25
Initial temperature of molten alloy/K	923·15	Die casting velocity (high speed)/m s^{-1}	2·0



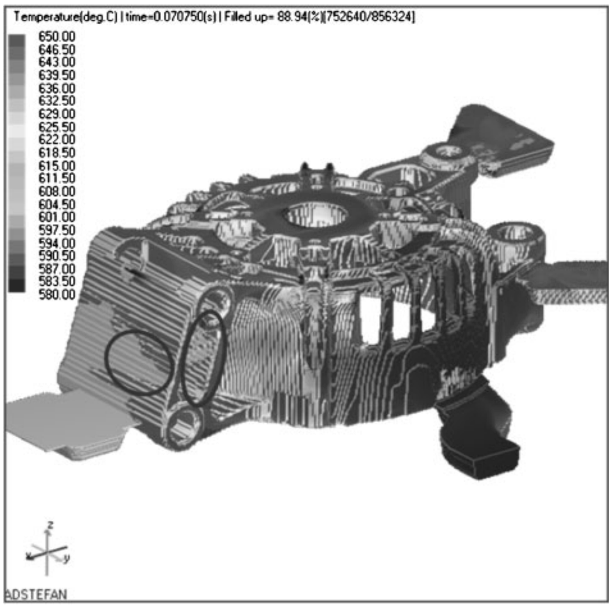
7 Fluid flow results and temperature distribution at filling time of 0·0346 s

Results and discussion

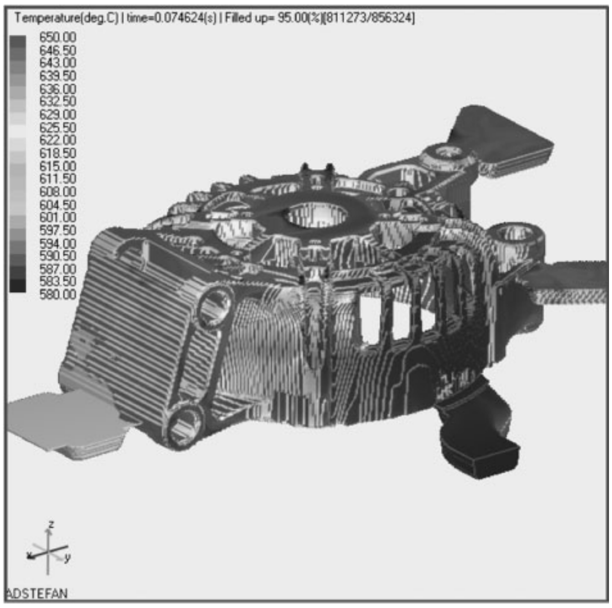
Casting results of single runner system

Aluminium alloy ADC12 was adopted in this study. ADC12 is the most commonly used aluminium alloy for die casting alloys. The composition of ADC12 is shown in Table 3, and die casting parameters are shown in Table 4.

The single runner system design was used to cast the top cover of an automobile generator, as shown in Fig. 3. The dimension of the die casting is about 22·5 × 15·6 × 8·4 cm. Defects were found on the casting surface, as indicated by A, B and C in the figure. A magnified view of the area with defects is shown in Fig. 4. Location A includes two kinds of defect, i.e. cold



8 Fluid flow results and temperature distribution at filling time of 0·0708 s

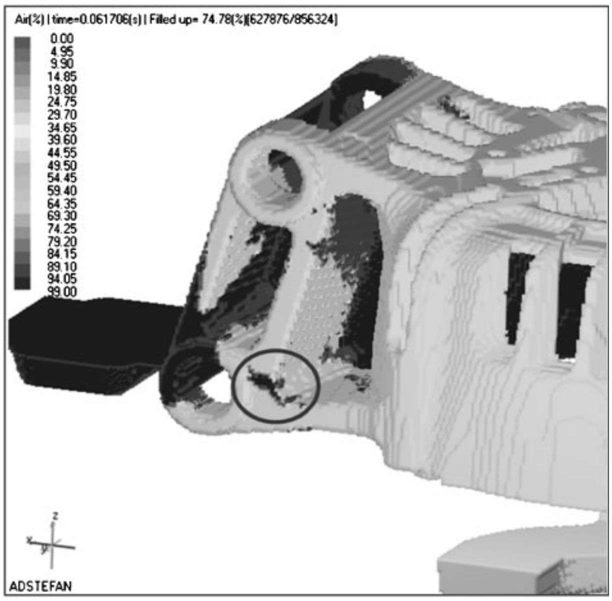


9 Fluid flow results and temperature distribution at filling time of 0·0746 s

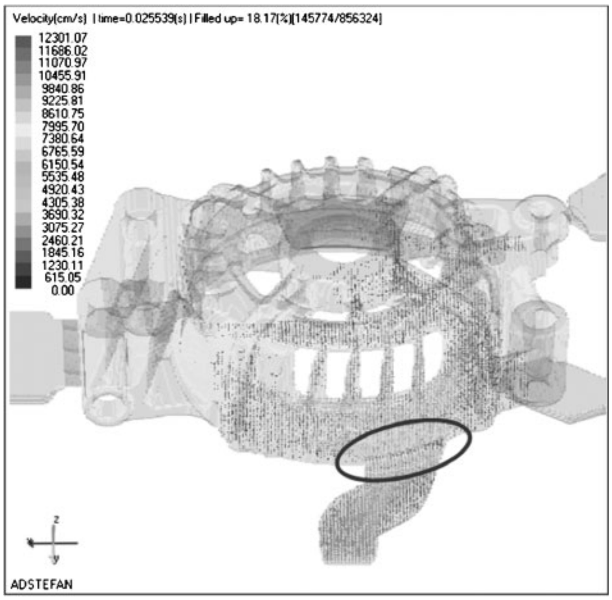
moire and filled undesirable, and locations B and C show filled undesirable.

Simulation results of single runner system

Numerical simulation was used to analyse the flow and temperature distributions of the molten alloy of the single runner system casting. The results are shown in Figs. 5–9. The cavity was filled to ~95% (Fig. 5). The filling order was quite asymmetrical, with the thicker part of the casting being filled last. The complete flow behaviour is shown in Figs. 6–9; the temperature distribution is expressed using colour during the filling period of 0·0001–0·0746 s. Because the temperature of the molten alloy did not drop uniformly in every area of the casting, it may cause premature solidification in the low temperature region. Early solidification prevented



10 Gas residual of filling process for die casting of top cover of automobile generator with single runner system



11 Velocity of fluid flow at gate of top cover of automobile generator with single runner system

the free movement of the semisolid metal, which resulted in hampered flow. In general, the last filled region of die casting is particularly prone to defect formation.[4] Large temperature drops may result in the cold moire defects.

Figure 9 shows the temperature distribution of the single runner system of die casting when the filling rate reached 95%. The temperature distribution is not very uniform. Comparing Figs. 5 and 9, the temperature ($\sim$883·15 K) of the final filling region of the casting is lower than that at other locations. The molten alloy filled the mould from top to bottom respectively, as shown in Fig. 8; the temperature at these marked areas was relatively low. Comparing the marked areas in Fig. 8 with locations A and B in Fig. 4, the cold moire defects on the surface can be clearly observed.

If air is trapped in the cavity during the die casting process, then air pocket defects are generated. Figure 10 shows the prediction of the location of air entrapment in the cavity during the die casting process. Air collected in the cavity and could not escape, as shown in the marked area in Fig. 10. The air pocket defects on the surface can be clearly observed in location C of Fig. 4. This validates the accuracy of the proposed numerical system.

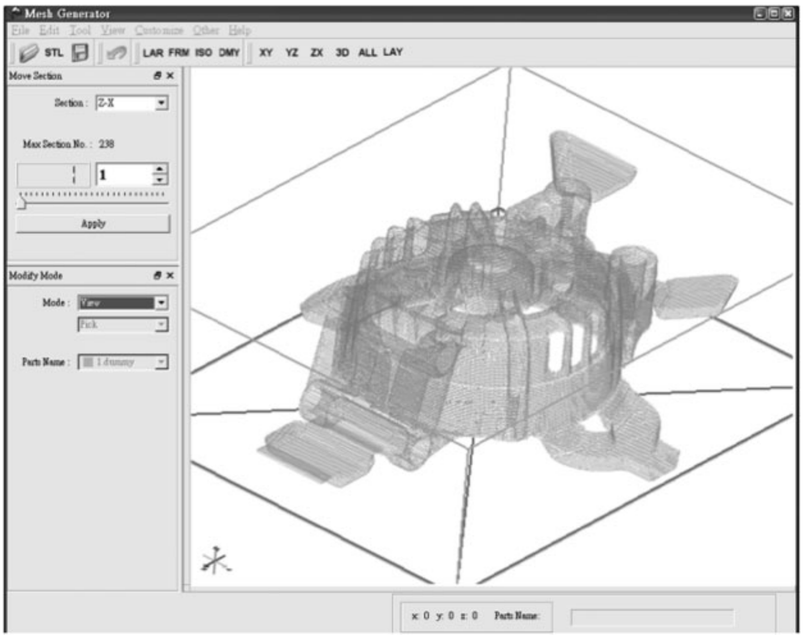
The flow behaviour of the molten alloy can be determined from the velocity distribution obtained during the filling process. It is related to whether air and surface oxide will be trapped in the casting and erosion on the die will be caused by the impact of the molten alloy. The gate of the single runner system casting with a velocity of $\sim$128 m s^{-1}, marked with a circle in Fig. 11, allows the die to be easily etched by the molten alloy.[5,6]

Simulation results of improved design

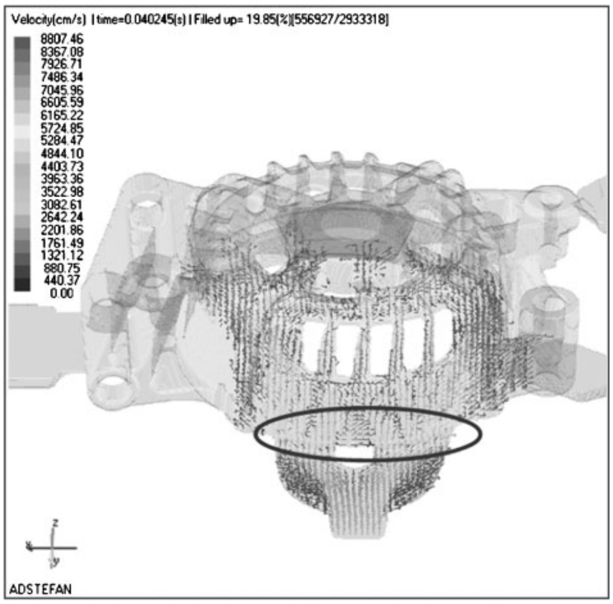
Under a given set of die casting parameters, the runner system design of the mould controls the fluid flow and distribution in the cavity. To enhance the flow stability and to reduce cold moire and gas entrapment, the molten alloy should be filled more symmetrically, and its temperature distribution should be more even in the cavity during the process of filling.

In order to eliminate defects and improve the quality of the casting, the single runner system of the original design was changed to a double runner system of the Y shaped design, as shown in Fig. 12. Because the gate area was increased, the velocity at the gate was reduced to $\sim$62 m s^{-1}, as shown in Fig. 13. Therefore, it can reduce the erosion situation by the molten alloy effectively.

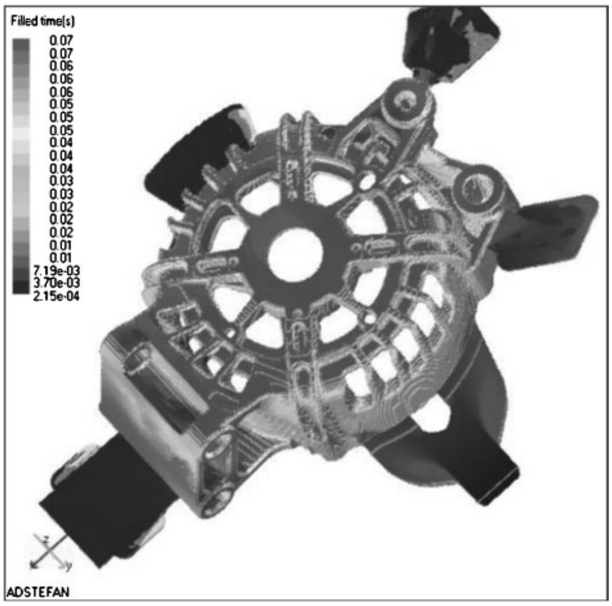
The cavity is filled to $\sim$95% in Fig. 14. The filling sequence of the double runner system is more symmetrically distributed for the whole casting as compared to that of the single runner system. Figure 15 shows the temperature distribution of the double runner system. The temperature distribution is more



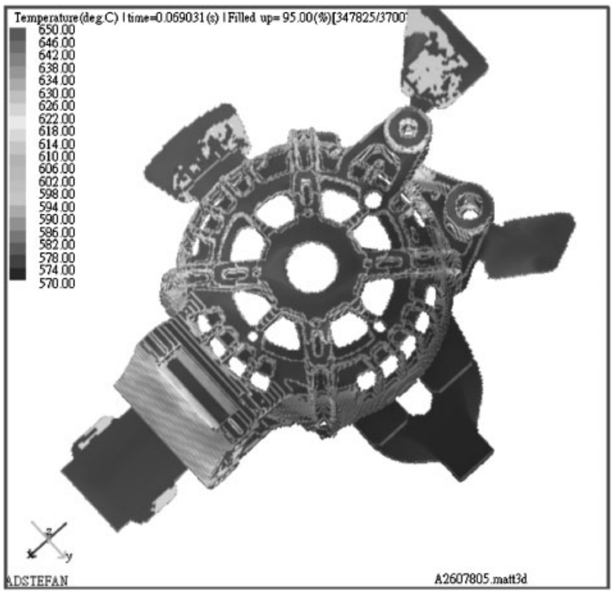
12 Mesh of double runner system



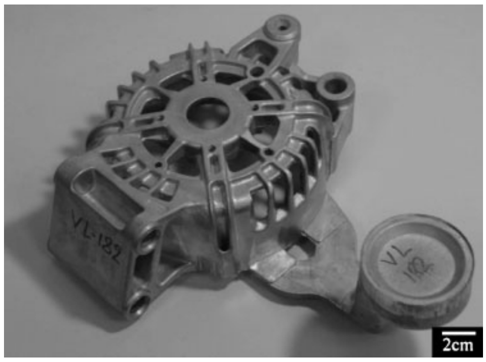
13 **Velocity of fluid flow at gate of top cover of automobile generator with double runner system**



14 **Filling time results of die casting of top cover of automobile generator with double runner system**



15 **Temperature distribution of top cover of automobile generator with double runner system at filling time of 0·069 s**



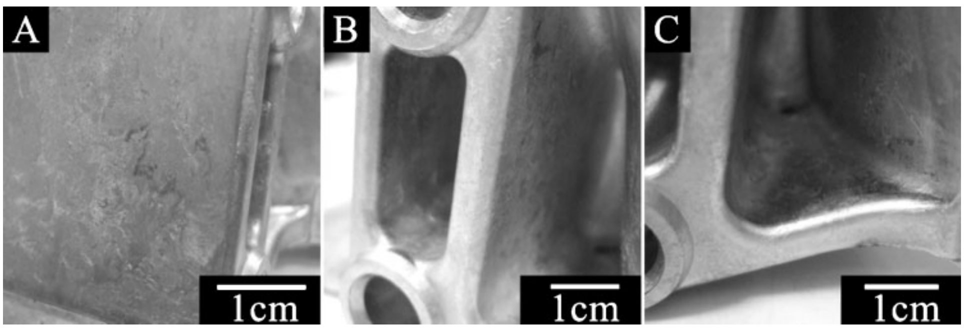
16 **Casting of double runner system**

uniform than that of the single runner system. The uniform temperature distribution reduces the number of cold moire defects, and a higher temperature helps the molten alloy to flow smoothly, reducing the number of filled undesirable.

Casting results of improved design

The simulation results showed that the fluid flow and the temperature distribution would be improved by the double runner system. The mould was changed to a double runner system and then applied to the die casting process. The casting of the double runner system is shown in Fig. 16.

The defects on the single runner system were compared with those on the double runner system, as shown in



17 **Improved surface defects of die casting of top cover of automobile generator with double runner system**

Fig. 17. The problems encountered with the single runner system were resolved using the modified mould.

Summary

1. The accuracy of the proposed numerical system was validated using practical casting experiments; the causes of defects can be identified by cross-checking the results.

2. The single runner system was replaced by a double runner system. The modified system significantly improved the quality of the die casting and eliminated the surface defects.

3. The replacement of the single runner system by the double runner system noticeably reduced the velocity of the molten alloy at the gate, which can extend the life of the die.

4. The use of a double runner system design enabled a more uniform distribution of temperature and improved the final filling in the casting process. The number of cold moire defects and the amount of gas entrapment were reduced.

References

1. P. O. Lafsson, R. Sandstro and As. Karlsson: *J. Mater. Sci.*, 1997, **32**, (16), 4383–4390.
2. A. Kaye: 'Die casting metallurgy', 23–41; 1982, London, Butterworth Scientific.
3. M. C. Flemings: 'Solidification processing', 181–183; 1974, New York, McGraw-Hill.
4. N. A. El-Mahallawy, M. A. Taha, E. Pokora and F. Klein: *J. Mater. Process. Technol.*, 1998, **73**, (1–3), 125–138.
5. Y.-B. Jiao and Y.-H. Wei: *Mech. Eng. Autom.*, 2008, **5**, 97–100.
6. M. T. Rowley (ed.): 'International atlas of casting defects', 46–47; 1979, Des Plaines, IL, American Foundrymen Society.

Copyright of International Journal of Cast Metals Research is the property of Maney Publishing and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.