A Knowledge-Based Flow Process Of Injection Molding in the Large Complicated Polymer Composite Manufacturing

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SUMMARY: A knowledge-based flow process is presented for the large body injection-molding technology that is a difficult technique because of many factors and its interactions during molding process. DOE(Design of Experiment) is used to construct the optimal mold design condition and molding process. CAE(Computer Aided Engineering) is used for obtaining the mold process analysis and design, and CAI(Computer Aided Instruction) is introduced for the results of production molding process. The flow process of large body is systematically planned and finally constructed the knowledge-based flow process with DOE, CAE and CAI. The proposed flow process is implemented for molding process of automobile front bumper facia. It is found that the proposed knowledge-based flow process

KEYWORDS: Knowledge-based flow process, Optimal design, DOE(Design of Experiment), CAE(Computer Aided Engineering), CAI(Computer Aided Inspection)

INTRODUCTION

Injection molding has high productivity with accuracy and forming capacity of component parts. The plastic injection molding process has been used widely for mass production. However, it is difficult to produce large parts by injection molding. They have some problems of productivity and accuracy in molding process, compared to molding of the small parts. The large body molding technology is consequential for production of modular parts such as automobile component parts and aerospace parts[1,2].

For example, large bodies contain automobile front and rear bumper and instrument panel, and so on. Recently, the more automobile parts are produced in modular parts, being formed by LIMBT(Large Injection-Molded Body Technology). DOE can extract main factors and interactions among the factors to identify properties of injection molding process. Integration of DOE and computer aided technology supports a knowledge-based flow process for mold design to production molding in large injection-molded body technology.

This paper proposes a knowledge-based flow process for LIMBT, which can applied to automobile parts, such as bumper and instrument panel and so on.

CAE AND CAI

CAE and CAI can find results of variables for molding and production process. CAE is applied to analyze mold design and molding process. The polymeric flows in the filling phase can be approximated to a Hele-Shaw model[3]. Assuming an incompressible and non-Newtonian fluid, the equations for the filling phase of polymer can be written as the below equations[4]. These equations are continuity equation, momentum equation, and energy equation, respectively.

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial \omega}{\partial z}=0 \tag{1}$$

$$\frac{\partial p}{\partial y}-\frac{\partial}{\partial z}(\eta\frac{\partial v}{\partial z})=0\,,\quad \frac{\partial p}{\partial y}-\frac{\partial}{\partial z}(\eta\frac{\partial u}{\partial z})=0 \tag{2}$$

$$\rho\, C_p(\frac{\partial T}{\partial x}+u\frac{\partial T}{\partial z}v\frac{\partial T}{\partial z})=\eta\gamma^2+k\frac{\partial^2 T}{\partial z^2} \tag{3}$$

where (*x, y, z*) are the Cartesian coordinates and (*u, v, w*) are the velocity components, respectively. *T* is the temperature, p is the pressure, ρ is the density, *Cp* is the specific heat and *k* is the thermal conductivity of the material whilst, η and γ are the shear viscosity and the shear rate.

CAI can be used to inspect the results of molding process and production process, which is corresponding to a follow-up experiment. The results to factors of injection-molded parts are found by the monitoring system and the 3D dimensional metrology. The 3D scanning inspections are based on 3 dimensional laser scanning and dimensional analysis. The measuring tolerances are within 20 ㎛ with space geometry operations. The dimensional accuracy of parts is analyzed, compared with the geometric model of parts to check shrinkage and dimensions of the parts as shown in Fig. 1.

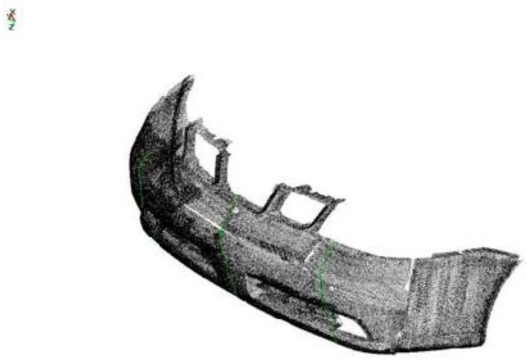


Fig. 1 3D scanning data and sectional dimension analysis

The monitoring system has pressure and temperature sensors, which are installed within the injection mold to detect molding temperature and pressure such as holding pressure and maximum pressure and temperature of melt polymer resins. The molding process factors are analyzed with the results calculated from CAE, and then compensated for accurate controlling the molding process and working conditions to construct a knowledge-based flow process. The monitoring system scheme is given in Fig. 2.

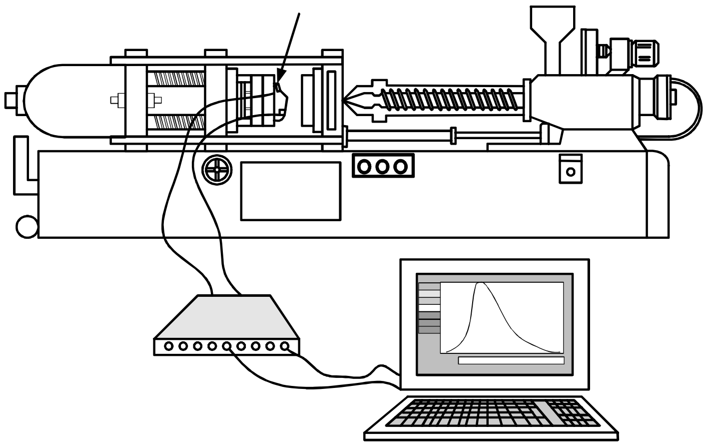
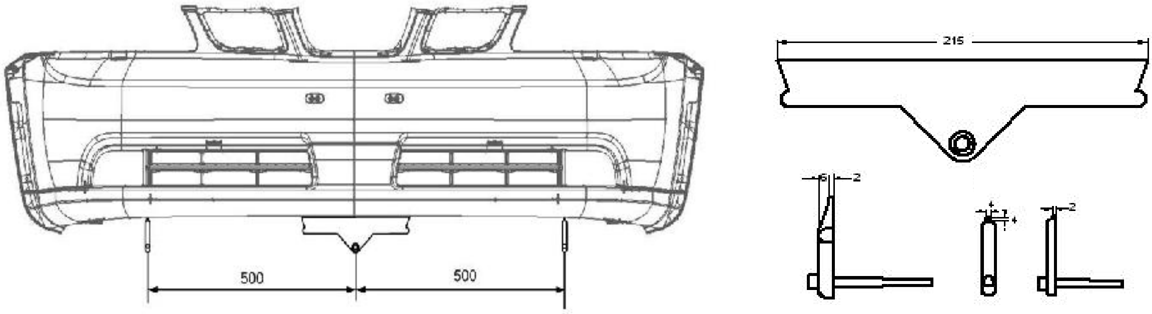


Fig. 2 Monitoring system scheme for injection molding process

DESIGN of EXPERIMENT

DOE has been used to systematically investigate process variables or product variables which can affect quality of parts. The DOE procedure consists of 4 steps: planning to define problems and objectives, screening to reduce the number of variables by defining the key variables, optimization to determine the optimal values and results for experiment factors, and verification to perform a follow-up experiment and confirm the optimal results.[5]

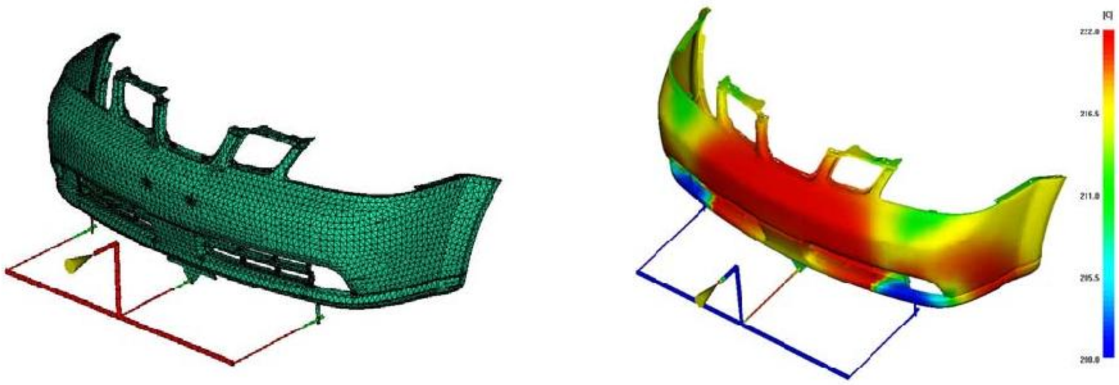
In mold design, main factors are main gate systems, side gate systems, and number of sub-gates, and so on. Fig. 3 shows gate systems and gate location. The geometrical shape and size of main gate and sub-gate are given with their location on the parts.



(a) Gate location (b) Gate systems

Fig. 3 Gate systems and gate location

Main factors of molding process are holding pressure and mold temperature, and so on. The molding process can be analyzed by CAE system with the given conditions. The mesh generation and process analysis are shown in Fig. 4. And, the other important factor is cooling system, which can determine cycle time and shrinkage, and so on. However, the cooling channel is expensive and complicated so that the cooling system is fixed. The cooling channel is not considered as main factors in this study. Fig. 5 shows the cooling channel of the bumper facial injection mold.



(a) Mesh generation (b) Analysis of molding process

Fig. 4 Mesh generation and analysis of molding process

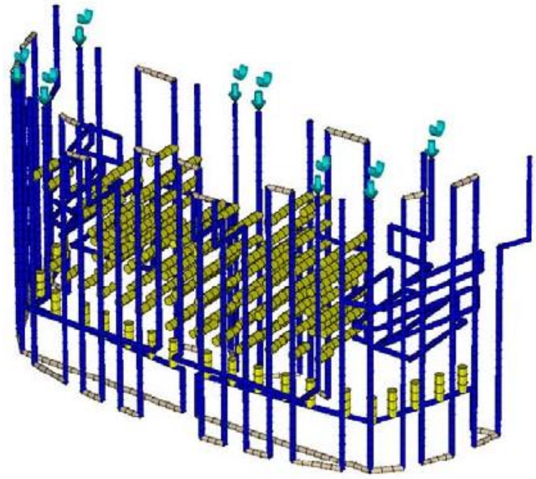


Fig. 5 Cooling channels of bumper facia injection mold

KNOWLEDGE-BASED FLOW PROCESS

The knowledge-based flow process is constructed on integration of computer aided technology and DOE. The DOE is applied in 3 steps; mold design process, molding process, and production process. Each step has many factors to affect the quality of its process. Results of DOE can be found by CAE in case of mold design process and molding process. And, Results of DOE in molding and production process is measured by CAI, which can measure values of variables in physical molding and production process. At the first time, main factors are simulated in 2 levels. The interactions among factors and main factors are selected. And then, the factors and interactions are simulated in 3 levels and repeat the previous process. For example, injection molding of bumper facia is planned and constructed based on the proposed knowledge-based flow process. Polymer resin of bumper is a kind of PP, reinforced with fiber to enhance physical properties. Table 1 explains the DOE in 3 steps of bumper facia.

Table 1 DOE schemes for injection molding of bumper facia

Items	Mold design process	Molding process	Production process
Main factors	Main runner system Sub runner system Gate system	Filling profiles Packing profiles Mold temperatures V/P change time	Injection pressure Injection velocity Packing profile Hot runner temperature V/P change time Metering volume Mold temperature difference
Level	2	2	3 or 2(mixed)
Orthogonal array	$L_8(2^7)$	$L_{81}(3^{40})$	$L_{18}(2\times3^7)$

CONCLUSIONS

The knowledge-based process of large injection-molded body is studied on integration of DOE and computer aided technology such as CAE and CAI. Large injection-molded body is complicated technology so that DOE are applied systematically in monitoring and controlling many factors of the process. CAE is applied in mold design process to optimize mold design and molding process. And, CAI is introduced in molding and production process to find optimal process conditions. For example, bumper facia reinforced with fiber is implemented on the knowledge-based process.

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